



Early development in segmenting word forms : rhythmic units, vowels and then consonants

Léo-Lyuki Nishibayashi

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ECOLE DOCTORALE 261
« COGNITION, COMPORTEMENTS, CONDUITES HUMAINES »

Développement précoce de la segmentation des formes sonores : unités rythmiques, voyelles puis consonnes

Early development in segmenting word forms:
Rhythmic units, vowels and then consonants

Thèse de Doctorat

Léo-Lyuki Nishibayashi

Discipline : Psychologie

Thèse présentée et soutenue publiquement le 18 novembre 2014 devant un jury composé de :

Laura Bosch	Professeur	Rapporteur
Caroline Floccia	Professeur	Rapporteur
Anne Christophe	Directrice de Recherche	Examineur
Pierre Hallé	Directeur de Recherche	Examineur
Thierry Nazzi	Directeur de Recherche	Directeur de thèse

Résumé

Les mots étant rarement produits hors contexte phrastique, les enfants vont devoir les extraire du flux de parole pour les apprendre. Les probabilités de transition (Saffran et al., 1996) et les unités rythmiques (Nazzi et al., 2006) seraient cruciales à l'émergence de la segmentation. Les formes sonores segmentées seront par la suite mémorisées en représentations phonétiquement détaillées. Cependant, selon Nespor et al. (2003) les consonnes seraient plus impliquées au niveau lexical que les voyelles, proposant un biais consonantique dans la reconnaissance des formes sonores segmentées.

Le premier axe de ma thèse s'intéresse aux capacités précoces de segmentation chez les enfants francophones nés à terme et prématurés afin de déterminer quand elles émergent et dans quelle mesure les unités rythmiques sont impliquées. Le second s'intéresse à l'émergence et à l'origine du biais consonantique.

Les résultats montrent que (1) les enfants nés à terme et prématurés sont capables de segmenter la parole en utilisant l'unité syllabique dès 6 mois ; (2) d'un biais vocalique à 6 mois, les enfants francophones, acquièrent un biais consonantique à 8 mois dans la reconnaissance de formes sonores segmentées ; (3) le biais consonantique proviendrait donc de l'acquisition des propriétés acoustiques/phonétiques de la langue maternelle.

Abstract

Since words are rarely produced in isolation, one of the first steps in acquiring new words is to segment them from continuous speech. Transitional probabilities (Saffran et al., 1996) and rhythmic units (Nazzi et al., 2006) have been proposed to be crucial at segmentation onset. Segmented word forms will then have to be stored as phonetically-specified representations for future recognition. However, Nespor et al. (2003) hypothesized that consonants, more than vowels, are involved at the lexical level, proposing a consonant bias in early word processing.

The first part of my dissertation investigates preterm and full-term infants' segmentation abilities to determine when they emerge and to what extent rhythmic units are involved. The second part investigates the emergence and origin of the consonant bias in recognizing segmented word forms with full-term infants.

Results show that (1) both preterm and full-term 6-month-olds are able to segment speech by using syllabic units; (2) French-learning infants switch from a vowel bias at 6 months to an adult-like consonant bias in recognizing segmented word forms; (3) the consonant bias emerging between 6 and 8 months of age, it would result from the processing and learning of the acoustic/phonetic properties on the language being acquired.

Le Maître Philosophe s'adressant à Monsieur Jourdain :

« Pour bien suivre votre pensée et traiter cette matière en philosophe,
il faut commencer selon l'ordre des choses, par une exacte connaissance de la nature des
lettres, et de la différente manière de les prononcer toutes.

Et là-dessus j'ai à vous dire que les lettres sont divisées en voyelles, ainsi dites voyelles
parce qu'elles expriment les voix;
et en consonnes, ainsi appelées consonnes parce qu'elles sonnent avec les voyelles, et ne
font que marquer les diverses articulations des voix.

Il y a cinq voyelles ou voix: a, e, i, o, u. »

Molière, Le Bourgeois gentilhomme, Acte II Scène IV

Acknowledgments – Remerciements

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GENERAL INTRODUCTION

1. Developmental psycholinguistics: objectives

Human language is one of the most complex aspects of cognition. Only humans are able to combine concepts and ideas to create new concepts and ideas in order to communicate. Numerous researchers agree that language is a human specific ability (e.g., what language does is to make it possible to share internal complex representations with others; Hockett, 1987). Although there are some similarities between animal and human communication abilities (e.g., vocal learning abilities in birds; Feenders, Liedvogel, Rivas, Zapka, Horita, Hara, Wada, Mouritsen, & Jarvis, 2008), only humans are able to produce an infinite number of sentences from a finite number of words. Cognitive psychology, and more precisely, psycholinguistics, investigates how humans perceive, produce and comprehend language. One crucial aim in psycholinguistics is to determine what is innate and what is acquired in language abilities. A second aim is whether the mechanisms used in adulthood differ from a language to another and when and how it is set into place. Several paths are available to researchers to study speech processing. One is to explore typical adults' abilities in speech perception/production using behavioral or electrophysiological methods. A second path is neuropsychology: by comparing healthy subjects to brain damaged subjects, or people with (developmental) disabilities/syndromes, the researchers can determine what the brain areas involved in speech processing are. Finally, a third path, which this dissertation follows, investigates language acquisition to answer the following general question: what are the first steps, filters and biases that will shape language acquisition from birth to adulthood? It is only this third path that can determine with precision the origins of language-related mechanisms. However, all these paths bring little by little a progressively richer explanation in how language is processed, how human-specific it is, and which mechanisms are innate or acquired.

Although language is also accessible with visual and motor mechanisms, speech is its main aspect available to infants. Speech sounds are special and are already processed differently from other sounds in newborns (Vouloumanos, Kiehl, Werker, & Liddle, 2001). This suggests an innate bias in perceiving language-related sounds and also the existence of particular characteristics that have to be distinguished from others to be considered as belonging to speech. Pre-wired for speech perception, infants first have language-general

perception abilities. Then, to understand their linguistic environment, they will have to acquire numerous patterns relevant within their native language. Thus, many changes occur at all levels of the linguistic hierarchy. Indeed, language is organized at different levels, including the prosodic level containing rhythm (which is already available in the mother's womb), the segmental level, corresponding to the phonetic/phonological units of speech such as consonants and vowels, the lexical level, corresponding to the words associated to their meanings and the syntactic level, defining the structure of speech (grammar). Therefore, many developmental studies have been conducted to discover what the early linguistic mechanisms are and how they develop to reach an adult-like state.

Our focus in the present dissertation concerns infants' early abilities to use specific characteristics of their native language in order to learn new words. While Experimental Chapter 1 will investigate the role of rhythmic units in segmenting speech, Experimental Chapter 2 will explore the emergence of a consonant advantage (consonant bias) in recognizing segmented word forms. Before presenting this research, we start by reviewing what we know regarding early prosodic and phonetic acquisition, followed by a review of the issues and knowledge regarding early word form representations.

2. Early speech perception: prosodic and phonetic acquisition

As learning a language requires determining what are the important cues contained in the speech signal that are perceived by infants, for more than 60 years, many studies have been focusing on exploring infants' perception of speech. While prosody is heard *in utero*, at birth, all the characteristics of speech such as segmental (e.g., phonemes), and subsegmental (e.g., coarticulation) cues become available. Consequently, at birth, newborns become immersed in a huge amount of new information. While perceiving speech, infants will thus have to extract and categorize relevant cues so that they can robustly process speech and have access to linguistic information: language acquisition is a dynamic process during which infants have to track numerous cues. Infants are thus remarkable computationalists (Kuhl, 2004). From distinguishing speech sounds from other sounds, they have to extract stable language-general characteristics of speech and further determine which of these characteristics are relevant in their native language. To

illustrate how infants develop their linguistic skills, Kuhl (2004) provided a timeline of speech perception and production during the first year of life (Figure 0.1.).

Figure 0.1. Timeline of speech perception and production development during the first year of life. From Kuhl (2004).

In the next sections, we describe a series of studies exploring how, from an initial language-general sensitivity to suprasegmental and segmental information, infants' perception of speech attune to their linguistic environment.

2.1. Prosodic level

Prosody usually refers to the suprasegmental cues of speech including stress, rhythm, duration, intonation, intensity and pitch. Because prosody is the only language-related information available before birth (Lecanuet, Granier-Deferre, Jacquet, & Busnel, 1992; Lecanuet, Granier-Deferre, Jacquet, & DeCasper, 2000; Granier-Deferre, Ribeiro, Jacquet, & Basserau, 2011), many researchers investigated very young infants' sensitivity to prosody, and its role in shaping speech perception in the first months of life, exploring whether or not infants are able to discriminate prosodically dissimilar stimuli.

2.1.1. Initial sensitivity to prosody at the sentence level

One of the earliest studies on prosody was carried out by Mehler, Jusczyk, Lambertz, Halsted, Bertoncini, and Amiel-Tison (1988). Aiming at determining if and how infants distinguish utterances in one language from another, Mehler et al. (1988) conducted a series of experiments to explore whether French-learning 4-day-old and English-learning 2-month-old infants are able to discriminate their own language from another on the basis of prosodic cues. French newborns were found to detect the difference between French sentences and Russian ones, and English-learning 2-month-olds were found to discriminate English versus Italian sentences. However, when presented with utterances of two unknown languages, neither newborns nor 2-month-

olds were able to discriminate the sentences. These results suggest that as young as 4 days of age, infants are able to discriminate two different languages when one of the two languages at test is the native language, hence that comparison between languages needed prior prosodic knowledge and actual comparison between the known and another unknown language. However, this study does not inform on the kind of prosodic information infants use to discriminate two languages. A decade later, Nazzi, Bertoncini, and Mehler (1998) provided evidence of rhythmic sensitivity in French newborns who showed discriminative capacities when presented with two languages belonging to two different rhythmic classes (stress-based English vs. mora-based Japanese) but not with two languages belonging to the same rhythmic class (English vs. Dutch).

In order to determine whether another cue than rhythm, namely intonation contained in prosody could have helped infants discriminate two different languages (Mehler et al., 1988; Nazzi et al., 1998), Ramus (2002) tested French newborns on a language discrimination task. Using the High-Amplitude Sucking (HAS) procedure, Ramus (2002) presented newborns with Japanese and Dutch stimuli. To further study the role of rhythm, Ramus (2002), using a speech resynthesis technique (*flat sasasa* manipulation, Ramus & Mehler, 1999), progressively degraded the speech signal so that the non-rhythmical properties of the stimuli were eliminated till obtaining only rhythmic cues. To degrade phonemic properties, all the consonants were mapped to /s/ and all vowels to /a/ (thus, also resulting in the suppression of phonotactic regularities) and to degrade intonation, the original phrasal fundamental frequency (F_0) contour was replaced with a constant F_0 . Even with this degraded speech signal, results showed that newborns can still discriminate two different languages. Thus, this finding showed that when deprived of intonational and phonemic cues (by synthetically degrading the stimuli) newborns were still able to discriminate the two languages at test solely on the basis of rhythm.

2.1.2. Initial sensitivity to prosody at the word level

As described above, infants were shown to be sensitive to the prosodic cues at the sentence level. What about the prosodic cues at the lexical level? While Ramus (2002) synthetically manipulated the speech signal to explore the role of prosody at the sentence level, investigating the role of prosody at the word level allows to better control the prosodic dimensions of the speech signal.

Nazzi, Floccia, and Bertoncini (1998), using the HAS procedure, explored whether French newborns were able to discriminate two different lists of Japanese words differing in pitch contour. Results showed that French newborns are able to discriminate words produced in a foreign language when varying in pitch contour, hence suggesting an initial sensitivity to pitch contour.

In addition, Sansavini, Bertoncini, and Giovanelli (1997) investigated newborns' perception of different stress patterns. When presented with multi-syllabic words carrying the accentuation on variable positions (e.g., *MAma* vs. *maMA*), Italian newborns were able to discriminate the two different word stress patterns. This finding thus establishes that newborns are also sensitive to lexical stress.

Another prosodic cue, involving pitch variations is lexical tone. Tones are primarily defined by the level and/or contour of the F_0 . In tonal languages, variations of F_0 occurring within syllables rise the tone cues to the lexical level. Variations in tone within a syllable can lead to different meanings. For example, in Mandarin, the word *ma* means *mother* when produced with a high level tone whereas it means *hemp* when produced with a rising tone. Thus, in tonal languages (e.g., Mandarin, Thai), the acquisition of lexical tones is crucial. Is the perception of tones following the same initial language-general sensitivity as stress? Although more studies in newborns' tone perception are needed, since lexical tone is partly defined by pitch contour, and knowing that French-learning newborns discriminate two different lists of Japanese words differing in pitch contour (Nazzi et al., 1998), it appears that newborns are sensitive to tone categories in a language-general manner from birth. Furthermore, Mattock and Burnham (2006) provide evidence that both English- and Chinese-learning 6-month-olds performed equally in lexical tone discrimination (lexical tones that were relevant for lexical discrimination for Chinese but not for English), hence supporting an initial language-general sensitivity for lexical tones at 6 months of age.

Taken together, these studies provide evidence of a language-general sensitivity to prosody from birth. Since some of these prosodic cues become relevant to correctly process speech in some languages but not in others, how do these initial prosodic sensitivities develop in infancy?

2.1.3. Developmental changes in prosodic perception at the sentence level

Bosch and Sebastián-Gallés (1997) examined the ability of 4-month-olds to identify their native language on the basis of prosody. The two languages at test were Spanish and Catalan. In one experiment, monolingual Spanish- and Catalan-learning infants were presented with utterances produced either in Spanish or in Catalan. Results showed that 4-month-old infants were able to distinguish the two languages from each other. However, Catalan and Spanish being phonologically similar, and to explore whether infants were able to discriminate the two languages belonging to the same rhythmic class (syllable-based) solely on the basis of prosody, Bosch and Sebastián-Gallés (1997) conducted other experiments in which the utterances from the two languages were low-pass filtered. Results of these experiments showed that infants could distinguish their native language from another one that is similar by relying on prosodic features. Thus, these findings establish that at 4 months, infants have finer prosodic perceptual abilities than newborns (Mehler et al., 1988; Nazzi et al., 1998) to discriminate two languages belonging to the same rhythmic class.

Moreover, similar results were obtained by Nazzi, Jusczyk, and Johnson (2000), showing that English-learning 5-month-old infants were able to discriminate English and Dutch sentences, Dutch and English belonging to the same rhythmic class (stress-based).

These studies thus demonstrate that infants from an initial language-general sensitivity to prosody at the sentence level become better at using finer prosodic features, suggesting a development of their abilities, tuned to the language of their native environment.

2.1.4. Developmental changes in prosodic perception at the word level

Given that infants are sensitive to prosody from birth, Jusczyk, Cutler, and Redanz (1993a) examined if and how the sensitivity to stress patterns of words might play a role in lexical development. To do so, they conducted a series of experiments in which 6- and 9-month-old English-learning infants were presented with lists of bisyllabic words following either a trochaic (strong-weak) or an iambic (weak-strong) pattern. Results showed that 9-month-old infants listened significantly longer to the trochaic lists compared to the iambic ones, suggesting a preference for the predominant rhythmic pattern of their native language. At 6 months, however, infants did not show any preference, suggesting that the preference for trochaic patterns develops as a result of

increasing familiarity with the predominant rhythmic pattern of their native language. Moreover, in a third experiment, English-learning 9-month-olds were tested with the same stimuli but low-pass filtered so that only the prosodic cues remained. Results in this experiment showed that even under these conditions, 9-month-olds preferred trochaic lists over iambic lists, suggesting that the preference they showed in the first experiment was specifically due to the prosodic structures of the words. Thus, Jusczyk et al. (1993a) showed that infants, from an initial sensitivity to prosody, acquire a preference for the predominant stress pattern (at the word level) of their native language between 6 and 9 months of age.

Similarly, German having the same predominant trochaic pattern at the word level as English, Höhle, Bijeljac-Babic, Herold, Weissenborn, and Nazzi (2009) investigated whether the trochaic bias emergence in German-learning infants followed the same developmental pattern as in English-learning infants (Jusczyk et al., 1993a). Furthermore, to assess whether the acquisition of a specific prosodic pattern was language-specific, they also tested infants acquiring French in which there is no contrastive stress patterns at the word level. Using HPP, Höhle et al. (2009) presented infants with sequences of the non-word *gaba* following either a trochaic (*GAbA*) or an iambic (*gaBA*) pattern. For German-learning infants, a trochaic preference was found at 6 months but not at 4 months, suggesting an emergence of the trochaic bias between these ages (thus earlier than the English-learning infants in Jusczyk et al., 1993a). For French-learning infants, no preference was found at 6 months, although they were able to discriminate the two stress patterns in another discrimination task. These findings indicate that German-learning infants begin to acquire their native stress pattern between 4 and 6 months of age, hence showing a language-specific reorganization to perceive the native stress pattern at the word level.

For tonal languages, Mattock and Burnham (2006) investigated whether lexical tone perception followed the same developmental pattern as described above. They tested English- and Chinese-learning infants at 6 and 9 months of age on a tone discrimination task. Mattock and Burnham (2006) found that while Chinese-learning infants performed equally well at 6 and 9 months, English-learning infants' ability to discriminate lexical tones diminished between these two ages. These results show that the perceptual reorganization for lexical tone depends on the native language environment.

Taken together, these studies show that infants, from an initial sensitivity to prosody, acquire specific prosodic patterns of their native language. Furthermore, the developmental pattern observed in English-, Chinese- and German-learning infants suggest that this acquisition occurs during the first year of life through experience to speech of their native language.

Suprasegmental cues such as prosody appear to be discriminated from birth and used later in infancy to process words. What about information that is available only from birth? Do segmental cues follow the same developmental pattern (initial sensitivity/discrimination to phonetic attunement helping word processing)? To explore this question, many researchers explored whether similar initial sensitivities are present for consonantal and vocalic phonetic information and how these sensitivities develop into more language-specific abilities.

2.2. Segmental level: consonants and vowels

2.2.1. Initial sensitivity to consonants

The original paper of Eimas, Siqueland, Jusczyk, and Vigorito (1971) provided the first evidence of early consonant discrimination in very young infants. They tested 1- and 4-month-old infants to observe whether at such an early age, infants have phonetic discrimination abilities. Using the non-nutritive sucking procedure, they presented infants with two syllables varying in one consonant contrast: voicing (/ba/ vs. /pa/). Their results showed that at both ages, infants were able to differentiate /ba/ from /pa/ (and the other way round) suggesting an early phonetic discrimination ability. Moreover, the infants were not able to discriminate two acoustically different utterances of a single syllable, suggesting categorical perception of consonants at 1 and 4 months of age. Because voicing is nearly universal, a discrimination ability between voiced and voiceless consonant contrasts also suggests a language-general sensitivity to consonants.

Later, many studies provided evidence supporting Eimas et al. (1971) first findings showing an initial sensitivity to consonants, in infants acquiring other languages (e.g., Streeter, 1976, for Kikuyu-learning infants; Kuhl, Stevens, Hayashi, Deguchi, Kiritani, & Iverson, 2006, for Japanese-learning infants) and importantly, with other consonant contrasts (e.g., Kuhl et al., 2006, for /r/-/l/ contrast; Narayan, Werker, & Beddor, 2010,

for /m/-/n/; Best, McRoberts, & Sithole, 1988, for Zulu contrasts; Werker & Tees, 1984, for Hindi and Salish contrasts).

However, Narayan, Werker, and Beddor (2010), showed that both English- and Filipino-learning 6- to 8-month-old infants fail at discriminating two syllables that differed by the Filipino contrast /ŋ/-/n/ while previous studies show discrimination of native and nonnative contrasts around the same age. This finding suggests that this particular Filipino contrast is difficult to discriminate for young infants regardless of their linguistic environment.

Taken together, these studies show that very young infants are sensitive to many consonant contrasts whether they are native or nonnative, suggesting a language-general sensitivity from birth. If the ability to discriminate consonant contrasts follows the same developmental pattern as early prosodic discrimination abilities, when does this language-general ability change into a language-specific capacity?

2.2.2. Developmental changes in consonant perception

Older infants were found to be able to discriminate different phonetic contrasts and seem to gradually change their phonetic-general perception into a more phonetic-specific perception. The work of Werker and Tees (1984) (but see also Werker, Gilbert, Humphrey, & Tees, 1981) illustrates this specialization. Indeed, they tested English adults and English-learning infants at two different ages on their ability to discriminate nonnative contrasts (Salish contrast: /k'i/ vs. /q'i/; Hindi contrast: /t,a/ vs. /ta/). English-speaking adults were unable to discriminate Salish and Hindi contrasts. Interestingly, around 6-8 months of age, English-learning infants were able to discriminate contrasts of Hindi and Salish that do not exist in their native language (Figure 0.2.). Later, around 10-12 months of age, infants presented an adult-like pattern, showing no discrimination between the contrasts in Hindi and Salish. Thus, these findings show a perceptual reorganization in discriminating phonetic contrasts, suggesting a specialization to the native language during the first year of life. "Citizens of the world" become "culture-bound" listeners (Werker & Tees, 1984) by learning the phonetic categories relevant in their native language. Note that Salish contrast discrimination was later replicated by Best and McRoberts (1989) with a different procedure, hence suggesting a phonetic attunement strong enough to be established with several procedures.

Figure 0.2. Discrimination of nonnative contrasts (Werker & Tees, 1984). Proportion of infant subjects from three ages reaching successful discrimination criterion on Hindi and Salish contrasts. From Werker & Tees (2002).

Similarly, Rivera-Gaxiola, Silva-Pereyra, and Kuhl (2005), using Event-Related Potentials (ERPs), showed that English-learning infants follow the same developmental pattern as the English-learning infants in Werker and Tees (1984). When presented with both English and Spanish contrasts, English-learning 7-month-olds' ERPs revealed discrimination of both native and nonnative phonetic contrasts while 10-month-olds' ERPs revealed discrimination for native contrasts only, thus, establishing the neural signature showing that English-learning infants become specialized for the perception of the contrasts of their native language between 7 and 10 months of age.

Of interest, this language-specific tuning is only evident for consonants that can be assimilated to phonetic categories of the native language. Indeed, while Best and McRoberts (1989) replicated the observation of a phonetic attunement between 6-8 months and 10-12 months using Salish and English contrasts, Best, McRoberts, and Sithole (1988) failed to show evidence of such attunement when adults and infants were presented with a Zulu click contrast: English adults and English-learning 6- to 14-month-old infants were able to discriminate the Zulu click contrast that is very unlikely to be used in their native language. Furthermore, these studies suggest that phonetic attunements do not mean that infants cannot perceive nonnative contrasts anymore.

Therefore, these studies indicate that there is a phonetic attunement to the consonants of the native language but also that this attunement has an impact on how older infants and adults perceive non-native consonantal contrasts. Indeed, according to the Perceptual Assimilation Model (PAM) proposed by Best (1995), once infants have acquired their native phonetic categories, they will use them as comparison points to perceive nonnative contrasts. Thus, according to PAM, depending on how nonnative contrasts will be assimilated or not to the native categories, older infants can still perceive and discriminate nonnative phones.

2.2.3. Initial sensitivity to vowels

Similarly to Eimas et al. (1971), Trehub (1973) explored whether 1- to 4-month-old infants are sensitive to vowel contrasts. Using the same non-nutritive sucking

procedure, infants were presented with a pair of syllables that differed by a vowel contrast (e.g., /pa/ vs. /pi/) or with a pair of vowels, (e.g., /a/ vs. /i/). Results showed that 1- to 4-month-old infants could detect vowel changes when these follow a consonant or when they occur alone. Thus, this finding, like Eimas et al. (1971) for consonants, provide evidence that very early on, infants are sensitive to vowel contrasts.

Cheour-Luhtanen, Alho, Kujala, Sainio, Reininainen, Renlund, Aaltonen, Eerola, and Näätänen (1995), using ERPs, also investigated whether initial sensitivity to vowels is present in newborns. They presented newborns with end points of the Finnish /i/-/y/ continuum and a “deviant” vowel which is reported as an /i/ or /y/ by Finnish-speaking adults. Results showed that the deviant vowel, when presented among standard /i/ and /y/, elicited a negative-going response resembling the adults’ mismatch negativity (MMN), hence suggesting that newborns discriminated the deviant and the standard vowels. Furthermore, this finding also suggest that vowels are perceived in a more continuous manner than consonants that are perceived more categorically. Thus, this finding confirms Trehub (1973) study, showing that infants are sensitive to vowels from birth.

Like consonant perception, infants are initially sensitive to vowels and given that vowels like consonants differ cross-linguistically, infants should also attune their vocalic perception through experience to their native language. However, since vowels carry prosodic information and thus are heard *in utero* (hence before consonants), does the linguistic specialization for vowel perception occur before that of the consonant?

2.2.4. Developmental changes in vowel perception

We mentioned above that vowels are perceived in a more continuous way than consonants in the sense that within categories vowel discrimination is better than consonant discrimination (Pisoni, 1973). This can also be observed in the magnet effect (Iverson & Kuhl, 1995). Adult studies showed that phonetic prototypes (best exemplars of a given phonetic category) act like perceptual magnet in speech perception. As a consequence, non-prototypic members of a category are perceived as more similar to the category prototype than to each other. This magnet effect was observed for vowels in English-learning 6-month-olds (Grieser & Kuhl, 1989). In order to investigate whether vowel perception follows the same developmental attunement as it is shown by Werker and Tees (1984) for consonants, Kuhl, Williams, Lacerda, Stevens, and Lindblom (1992) tested English- and Swedish-learning 6-month-olds on their perception of native versus

nonnative vowels. The rationale was that if 6-month-old infants have already attuned their vowel perception to their native language, the magnet effect for native and nonnative vowels should be different. Results showed that when presented with non-prototypic vowels, the magnet effect was stronger for native vowels than for nonnative vowels that is, Swedish-learning infants had a stronger magnet effect with Swedish vowels than with English vowels and conversely, English-learning infants had a stronger magnet effect with English vowels than with Swedish ones. This finding thus establishes that by 6 months, infants have already attuned vowel perception to their native language and exhibit a language-specific pattern in vowel perception.

Similarly, Polka and Werker (1994), tested English-learning 4- and 6-month-olds on German vowel contrasts discrimination. While 4-month-olds were found to discriminate the nonnative vowel contrasts, 6-month-olds could not, hence confirming previous results obtained by Kuhl et al. (1992).

Taken together, the above findings first suggest that from an initial sensitivity to consonant and vowel contrasts (Eimas et al., 1971; Trehub, 1973), there is a phonetic specialization to the native language. Second, they also establish that this specialization emerges earlier for vowels than for consonants. Third, that attuned phonetic categories will serve as referents to perceive nonnative contrasts in older infants (Best, 1995).

It appears that learning the native language needs prerequisites: initial sensitivity to suprasegmental (prosody) and segmental (phonetic) cues and the acquisition of the native patterns of these cues to correctly encode and represent early segmented word forms. As we will see, the present dissertation explored word segmentation with the ultimate goal of specifying the origin of the proposed consonant bias in lexical processing (Nespor, Peña, & Mehler, 2003). Thus, we will first describe how researchers came to propose a consonant vowel asymmetry in speech processing and then we will describe how and when early segmentation abilities emerge.

3. Consonants and vowels

It is generally considered that two phonetic categories are present across languages: consonants and vowels. These two categories differ by many aspects that we describe in the following paragraphs.

First, at the acoustic level, according to the International Phonetic Association (1999), consonants are sounds involving the closure (or the near closure) of the vocal tract. In contrast, vowels are sounds involving an open vocal tract. More precisely, a sound in which the air flow out of the mouth is disrupted, is considered to be a consonant. Consequently, the realization of consonants and vowels depends on numerous motor mechanisms along the vocal tract (Figure 0.3.). Thus, at the acoustic level, energy, duration and pitch vary greatly between consonants and vowels: vowels tend to be longer and have more energy than consonants (Repp, 1984; Ladefoged, 2001). This makes them more salient at the acoustic level and more easily perceivable *in utero* (Granier-Deferre, Ribeiro, Jacquet, & Bassereau, 2011), hence leading newborns to have a greater experience to vowels compared to consonants. More recently, Bouchon, Floccia, Fux, Adda-Decker, and Nazzi (in press) also provided evidence that on the one hand, vowels are more salient than consonants and on the other hand, that consonants are more discriminable than vowels if normalized in intensity and duration.

Figure 0.3. Side view of the vocal tract and its components necessary to speech production (retrieved from <http://www.indiana.edu/~hlw/PhonUnits/vowels.html>).

Second, at the perceptual level, several studies investigated how consonants and vowels are perceived by testing adult subjects, for example using phoneme identification/categorization tasks. In these studies, subjects were generally presented with a series of synthetic speech sounds, differing from each other by very small steps on a single acoustic dimension. These acoustic variations resulted in continua where the extremities corresponded to two phonemically distinct syllables (e.g., /ba/ and /ga/). The general question was: how are the stimuli perceived along these continua? Subjects were asked to label each sound in this series. Results show that consonants are processed more categorically than vowels (Fry, Abramson, Eimas, & Liberman, 1962; Liberman, Harris,

Hoffman, & Griffith, 1957). Indeed, while adult subjects organized the consonant sounds in three well-defined categories, showing sharply marked boundaries between each consonant class (/b/, /d/ and /g/, Liberman et al., 1957), it appears that the phoneme boundaries in the case of a three-vowel identification task (/I/, /ε/, /æ/) are less sharply defined (Fry et al., 1962). As illustrated in Figure 0.4., the vowel identification curves follow gradual slopes whereas the consonant identification curves follow more abrupt slopes.

Figure 0.4. Consonant and vowel identification (Liberman et al., 1957; Fry et al., 1962). Percent of consonants (from Liberman et al., 1957; left panel) and vowels (from Fry et al., 1962; right panel) identification.

Third, at the typological level, among the 7000 languages, with nearly 4000 spoken by small tribes in two tropical areas (one extending across Africa from the Ivory Coast to the Congo and beyond, and the other centered on Papua New Guinea; see Ladefoged, 2001), there is a clear tendency for consonants to be more numerous than vowels. That is one striking difference between consonants and vowels, resulting in different consonant/vowel ratios across languages as shown in Figure 0.5. illustrating the C/V ratios for 564 languages analyzed. Indeed, most of the linguistic systems have over 20 consonants with five-vowel systems being the most common (Maddieson, 1984; Ladefoged & Maddieson, 1996). Cases like Swedish or Danish with more vowels than consonants are very rare (16 consonants and 17 vowels for Swedish, International Phonetic Association, 1999; 15 consonant and 21 short and long vowel phonemes for Danish, Grønnum, 2005). Note also that some linguistic differences between consonants and vowels are present in Semitic languages, showing that lexical meaning is mainly supported by consonantal roots. Indeed, in these languages, lexical roots are formed almost exclusively by consonants while vowels are inserted to indicate morphological patterns (e.g., the *ktb* root, referring to 'write' in Arabic, can be declined into many words linked to the 'write' semantic root, McCarthy, 1985). Given that consonants are more numerous than vowels, and that they can vary more than vowels within words, they tend to disharmonize within a word and thus become more distinctive than vowels (Nespor et al., 2003; McCarthy, 1991; Itô & Mester, 1986). At the lexical level, Keidel et al. (2007), by analyzing almost 5000 CVCVCV words in French, showed that among these selected

words, there were 820 unique three-consonant tiers and 562 unique three-vowel tiers, thus allowing to choose from a larger number of consonants than for vowels. This analysis suggests that the informativeness of consonants is higher than that of vowels at the lexical level. In contrast, vowels tend to lose their distinctiveness: contrary to consonants, they tend to harmonize within lexical items and in some languages, vowel harmony is used to signal morphosyntax (see Nespor & Vogel, 1986 for Turkish example). But vowels also tend to lose their distinctive quality in unstressed position, contrary to consonants.

Interestingly for our concern, Ramus, Nespor, and Mehler (1999) reported that the percentage of vowels (calculated as the total duration of vocalic intervals in the sentence and divided by the total duration of the sentences) and the standard deviation of consonantal intervals within a sentence appeared to be directly related to syllabic and rhythmic structure of speech, hence leading the different organizations of languages into different rhythmic classes.

Figure 0.5. Consonant/vowel ratio across 564 languages (Maddieson, 2013). Numbers in square brackets represent how many languages are contained in each category. From the World Atlas of Language Structures Online (<http://wals.info/feature/3A#2/19.3/152.8>).

4. Functional specialization of consonants and vowels

4.1. The *division of labor* hypothesis

Taken together, the facts reviewed in the previous section show that consonants and vowels are physically different, but also that they are processed differently at different linguistic levels across languages. Based on the above differences between consonants and vowels and on some of the studies reviewed in the next sections, Nespor et al. (2003) proposed the *division of labor* hypothesis according to which there is a functional asymmetry between consonants and vowels. This hypothesis proposes two biases in processing speech: a consonants bias (C-bias) at the lexical level and a vowel bias (V-bias) at the prosodic and syntactic levels. The C-bias hypothesis proposes that consonants better identify the lexical entities of a given language and thus would be

preferentially used/tracked to identify words. In contrast, the V-bias hypothesis proposes that vowels mark the prosodic and grammatical properties of a specific language, and thus would be preferentially processed to extract syntactic rules and identify rhythm. Before getting into more details regarding the C-bias which is studied in the present dissertation, we present three related studies that illustrate this functional asymmetry.

Regarding the C-bias at the word level, Bonatti, Pena, Nespor, and Mehler (2005) used a word segmentation task to investigate whether consonants and vowels are differently involved in extracting words from the speech stream. Bonatti et al. (2005) presented French-speaking adults with artificial speech streams and then, at test, asked them whether a given word “looked” as belonging to the artificial language they were familiarized with. In order to compare the role of consonants and vowels in segmenting speech and knowing that transitional probabilities (TPs) at the syllabic level help in such a task (Saffran, Newport, & Aslin, 1996a), TPs were manipulated so that they were carried either by the consonants or the vowels. Results showed that while participants were able to determine that a word belonged to the familiarized artificial language when TPs were carried by the consonants, they could not do the segmentation task when TPs were carried by the vowels. These results suggest that when segmenting an artificial language, adults can track TPs when carried by consonants but not when carried by vowels. Thus Bonatti et al. (2005) provided evidence of a consonant advantage (C-bias) in a lexically-related task.

Even though vowels are acoustically more salient than consonants as mentioned above (see also Mehler, Dupoux, Nazzi, & Dehaene-Lambertz, 1996), consonants were preferentially processed to extract potential words. Interestingly, this consonant/vowel asymmetry appears to be specifically human. Indeed, Newport, Hauser, Spaepen, and Aslin (2004), using a segmentation task as in Bonatti et al. (2005), clearly demonstrated that non-human primates (tamarin monkeys) rely on TPs carried by vowels and not by consonants. Therefore, for tamarins, vowels and consonants would be processed solely on the basis of their acoustic saliency. Findings that human adults rely more on consonants than vowels at the lexical level might thus reveal that they process speech at a higher cognitive level than the purely acoustic level as shown by tamarins.

Regarding the V-bias hypothesis, vowels rather than consonants would be more involved at the prosodic and syntactic levels. Toro, Nespor, Mehler, and Bonatti (2008) tested adults to explore whether they were able to generalize a syntactic rule (e.g., ABA)

and segment words on the basis of TPs. For that purpose, adults were presented with speech streams containing non-words in which informative TPs were carried either by consonants or vowels and syntactic information (the ABA rule) was carried either by vowels or consonants. The rationale was that if adults present a functional asymmetry as suggested by Nespor et al. (2003), they should rely on consonants to extract words (C-bias in word segmentation) and they should rely on vowels to extract the syntactic rule (V-bias in generalizing rules). Results showed that adults used consonants to extract the words and vowels to extract the structural generalization. This study thus confirms Bonatti et al. (2005) evidence of a consonant advantage at the lexical level, and add evidence of a vowel advantage at the syntactic level, as suggested by the division of labor hypothesis (Nespor et al., 2003).

Importantly, Nespor et al. (2003) hypothesized that these biases (C-bias for lexically-related tasks and V-bias for prosodically/syntactically-related tasks), if present early in development, would help infants organize the huge amount of information contained in the speech input and facilitate language acquisition. Thus, consonants would help in the acquisition of the lexicon, and vowels would help in the acquisition of native prosody and syntax. The current dissertation focuses only on the C-bias and explored 1) whether it is present during the first year of life and 2) what its origin is. In the following, we review in more details what we know about the C-bias in lexical processing from infancy to adulthood.

4.2. C-bias in lexical processing: evidence from adults

Many adult studies explored the C-bias and found greater reliance on consonants than vowels in numerous lexical tasks: word learning (Havy, Serres, & Nazzi, 2014; Creel, Aslin, & Tanenhaus, 2006), word segmentation (Bonatti et al., 2005; Toro et al., 2008), oral and written lexical access (New, Araùjo, & Nazzi, 2008; New & Nazzi, 2014; Acha & Perea, 2010; Delle Luche, Poltrock, Goslin, New, Floccia, & Nazzi, 2014), and word reconstruction (Cutler et al., 2000; van Ooijen, 1996).

In word reconstruction tasks, van Ooijen (1996) and Cutler, Sebastián-Gallés, Soler-Vilageliu, and Ooijen (2000) investigated whether consonants are more involved than vowels in retrieving words from the lexicon. English (van Ooijen, 1996), Spanish and Dutch (Cutler et al., 2000) adults were presented with non-words (e.g., *kebra*) and were

told to change a single phoneme to transform the non-words into actual words (e.g., *cobra* or *zebra*), existing in their native lexicon. The researchers measured both adults' accuracy levels and reaction times. Results showed that when presented with non-words, participants were more inclined to change the vowel (*kebra* → *cobra*) than the consonant (*kebra* → *zebra*) and that they were faster and more accurate when they were constrained to make a vowel substitution than a consonant substitution. These studies thus provide evidence of a clear advantage of consonants over vowels in word reconstruction tasks. Moreover, this finding was observed in three different languages, hence supported the initial proposal that the C-bias is language-general (Nespor et al., 2003).

New, Araùjo, and Nazzi (2008) also explored the differences in processing consonants and vowels in a written lexical decision task. In this study, using a priming procedure, adult subjects were asked to judge if a target item was a real word or a non-word. Four types of primes were presented: 'identity prime' (e.g., *joli* preceded the target word *joli*), unrelated primes (e.g., *vabu*), consonant-related primes (e.g., *jalu*) and vowel-related primes (e.g., *vobi*). Subjects had faster reaction times when judging if the target was a real word or not with consonant-related primes than vowel-related primes. Evidence of the C-bias was thus found with a priming effect for consonant-related primes: consonants, more than vowels, facilitated lexical access.

More recently, using the same procedure and the same stimuli as New et al. (2008), New and Nazzi (2014) investigated whether the C-bias observed in New et al. (2008) had an orthographic or a phonological/lexical nature. Additionally, they also explored whether vocalic priming effects could be obtained by varying the duration of prime presentation. In a first experiment, following the same priming conditions as in New et al. (2008), New and Nazzi (2014) shortened the duration of prime presentation from 50 ms to 33 ms. Thus, if a priming effect emerges, it can only be due to the orthographic level. Results showed no significant difference between vowel and consonant conditions suggesting that the C-bias needs more time to emerge and thus is not orthographic-based. In the subsequent experiments, New and Nazzi (2014) investigating whether a priming effect by vowels can be observed, showed that adults always present a C-bias and if anything, increased primes lead to inhibiting priming effects by vowels. At any rate, these findings provide evidence of a consonant advantage in lexical processing, by showing that adults weight differently consonant and vowel information.

Extending this work to the auditory modality, Delle Luche, Poltrock, Goslin, New, Floccia, and Nazzi (2014) tested French and English adults on a lexical decision task in different priming conditions: consonant-related, vowel-related and unrelated conditions. As New et al. (2008), results showed that, overall, both English and French listeners had a larger priming effect in the consonant-related condition than in the vowel-related condition. These results extend New et al. (2008) findings to the auditory modality, and extend the evidence of a C-bias in lexical processing to English listeners, hence supporting the proposal that the C-bias might be present cross-linguistically (Nespor et al., 2003).

At the brain level, Carreiras, Vergara, and Perea (2007) investigated how consonants and vowels are processed in written lexical decision tasks. Spanish adult subjects were visually presented with 4 types of pseudo-words. For one target word (e.g., REVOLUCIÓN [revolution]), 2 sets of pseudo-words were created: a consonant-transposed pseudo-word (e.g., RELOVUCIÓN) and its corresponding vowel-transposed pseudo-word (e.g., REVULOCIÓN); a consonant-replacement pseudo-word (e.g., RETOSUCIÓN), and its corresponding vowel-replacement pseudoword (e.g., REVALICIÓN). Carreiras et al. (2007) then measured the N400 elicited for each type of pseudo-word. The N400 is generally measured to study lexical-semantic processing of words: the more important the N400 amplitude, the more distant the pseudo-word is considered to its corresponding actual word. First, results revealed that pseudo-words created by transposing/replacing consonants had slower latencies than pseudo-words created by transposing/replacing vowels, hence suggested a slower processing when consonants were changed compared to vowel changes processing. This pattern might be due to the fact that word recognition is more disturbed/disrupted when consonants (rather than vowels) are changed. Second, replaced-letter pseudo-words elicited larger negativity compared to transposed-letter pseudo-words, suggesting that transposed-letter pseudo-words were considered to be closer to actual words than replaced-letter pseudo-words. Finally, and more importantly, there were differences in the N400 amplitude when comparing consonant- and vowel-replacement/transposition and this differential pattern for consonants and vowels was also visible as the N400 was differently distributed on the scalp for consonant and vowel conditions. The difference in amplitude thus suggests that consonant and vowel changes were processed differently and the topographic distribution suggests that consonant and vowel changes involved different brain areas. Therefore, at the word level, consonants and vowels appear to be

processed in different functional ways. This consonant/vowel asymmetry in speech processing was observed with similar ERPs in different studies showing that consonants appear to be processed differently than vowels (Carreiras et al., 2007; Vergara-Martinez et al., 2011) and seem to involve different brain areas (Carreiras & Price, 2008; Caramazza, Chialant, Capasso, & Miceli, 2000).

Finally, using an eye-tracking method, Havy, Serres, and Nazzi (2014) tested French adults in a word-learning task. In this study, adults had to learn new label-object pairings: during the learning phase, two objects appeared on a screen and were labeled. These labels differed either by one consonant (e.g., /byv/ - /dyv/) or one vowel (e.g., /gyɜ/ - /guɜ/). During the test phase, participants were shown the pair of objects seen in the learning phase and halfway through the test phase, they heard the label of one of them (the target, the other object being thus considered as a distractor). The test phase was thus divided in two parts: the pre-naming and post-naming phases. The authors measured adults' looking times to the images in both the pre- and post-naming phases, an increase in looking times towards the target between the pre- and post-naming phases attesting word recognition. Results showed that adults succeeded in learning word-object pairings with both consonant- and vowel-contrasting labels. However, while there was no significant difference between consonant and vowel contrasted labels when analyzing the percentage of looking times to the target objects during the post-naming phase, latencies revealed faster detections of the label mismatch when participants were initially looking at the distractor in the consonant condition than in the vowel condition. Thus, Havy et al. (2014) found evidence of a C-bias in word learning with French adults, and this bias appears to constrain lexical decision timing.

Similarly, using an artificial language learning paradigm, Creel, Aslin, and Tanenhaus (2006) established that English-speaking adults confuse newly learned words less often when they differ by their consonants (e.g., *pibo* – *diko*) than when they differ by their vowels (e.g., *pibo* – *pabu*), suggesting that the consonants were better processed than the vowels in the new words. Thus, Creel et al. (2006) also provide evidence of a C-bias in a word learning task with English-speaking adults.

Taken together, these studies on adults showed a C-bias and thus support the division of labor hypothesis (Nespor et al., 2003). Moreover, this bias was found in several languages (e.g., French, English, Spanish, Dutch), hence supporting the idea that the C-bias might be present cross-linguistically although more languages should be tested in the

future. Given these findings, can we find evidence of a C-bias in lexical processing during development?

4.3. C-bias in word learning and familiar word recognition: evidence from French- and Italian-learning toddlers

In this context, many studies started to explore the role of the C-bias in development, to determine whether the C-bias influences and shapes early word learning/recognition during the second year of life. Several studies have been conducted in French- and Italian-learning toddlers. The first study was carried out in French-learning 20-month-olds (Nazzi, 2005). In this study, toddlers were tested using an interactive learning task, namely, the name-based categorization task (NBC task developed by Nazzi & Gopnik, 2001). In each trial, during a presentation phase, infants were presented with three new objects, two of them receiving the same label and the third receiving another label differing by a minimal or a more pronounced phonetic contrast (all the labels were non-words; see Figure 0.6.). During a test phase, toddlers were then asked to give the object that received the same label as the object held by the experimenter. Toddlers were considered to succeed, hence to have correctly learnt the object-label pair, when they gave the similarly labeled object. The rationale, if the C-bias is present at that age, was that infants should succeed in the consonant conditions where the object labels were consonantally contrasted, but not in the vowel conditions where the object labels were vocally contrasted. In this series of experiments, 20-month-olds performed better in the consonant conditions than in the vowel conditions, establishing a C-bias in learning new label-object pairings: at that age, French-learning toddlers appear to give more weight to consonants than vowels in learning new words (and their mappings).

Contrast changed		1 st & 2 nd objects	3 rd object
Consonant	Minimal	/pize/	/tize/
	Minimal	/pide/	/pige/
	Minimal	/pize/	/pyze/
Vowel	More Pronounced	/pize/	/paze/
	More Pronounced	/pize/	/pizu/

Figure 0.6. Experimental design in Nazzi (2005) using the name-based categorization task.

To further investigate the age of emergence of the C-bias, and because the NBC task was too complicated for infants younger than 20 months of age, other studies were conducted with a simplified version of this word-learning task: since the NBC task constrains toddlers to learn and then categorize the object-label pairs, the simplified version took away this categorization aspect. Indeed, instead of asking the child “give me the object that goes with this one”, the experimenter asked the child to “give me the (e.g.) *pize*”. Using this simplified version, Havy and Nazzi (2009) found evidence of a C-bias similarly to Nazzi (2005) but with French-learning 16-month-olds. This C-bias was also found in older French-learning children at 3, 4 and 5 years of age and adults (Havy, Serres, & Nazzi, 2014). However, this evidence of a C-bias was found in tasks involving toddlers’ learning of new words. What about simpler tasks like word recognition? Can a C-bias be observed at a younger age?

Zesiger and Jöhr (2011) tested French-learning 14-month-olds in a familiar bisyllabic word recognition task. In each trial, while seated in front of a screen, toddlers were presented with pairs of known object images (e.g., stroller, teddy bear, shoe). Then, they heard one of the object label either correctly pronounced or mispronounced. The mispronunciations corresponded either to a consonantal contrast (Experiment 1; e.g., /**p**usɛt/ [stroller] vs. /**m**usɛt/) or to a vocalic contrast (Experiment 2; e.g., /bebe/ [baby] vs. /bebẽ/). Moreover, Zesiger and Jöhr (2010) manipulated the position of the mispronunciations within a word, which occurred either in the initial (e.g., /**p**usɛt/-/m**u**sɛt/; /p**u**sɛt/-/p**ũ**sɛt/) or the final syllable (e.g., /fo**s**ɛt/-/fo**f**ɛt/; /bebẽ/-/bebẽ/). The rationale was that if toddlers consider the mispronunciation as a bad exemplar of the familiar word, then they should look less to the image corresponding to the correctly pronounced word. The authors measured toddlers’ looking times to the images in both the pre- and post-naming phases, an increase in looking times towards the target between the pre- and post-naming phases attesting word recognition. Results showed that in the consonant condition, toddlers looked significantly longer to the target compared to the distractor. In the vowel condition, toddlers looked equally to both objects. This finding suggest that French-learning 14-month-olds have a C-bias in processing familiar words. The authors reported a significant effect of the position where the mispronunciation occurred: in the consonant condition, toddlers appeared to detect the mispronunciation

only when occurring on the final syllable whereas in the vowel condition, toddlers appeared to detect the mispronunciation for both syllables.

Lastly, Hochmann, Benavides-Varela, Nespor, and Mehler (2011) tested Italian-learning 12-month-olds to investigate whether they also exhibit a C-bias. In this study, infants were evaluated on their ability to pair two objects to two non-words, as in Nazzi (2005), but using a different task. Infants were first familiarized to learn two object-label pairings (Figure 0.7. e.g., left side object associated with /dede/ and right side object associated with /kuku/). Then, in the test phase, infants were presented with two words: one was constituted by the consonants of the first name and the vowels of the second and the other was constituted by the consonants of the second name and the vowels of the first. For example, if the familiarization words were /dede/ and /kuku/, the test words were /dudu/ and /keke/. The rationale was that if infants have a C-bias, hence give more weight to consonants compared to vowels in learning the words, they should look longer to the side predicted by the consonants rather than the side predicted by the vowels. Results showed that 12-month-olds looked preferentially to the side predicted by the consonants, hence extending the C-bias in learning new object-label pairings to Italian-learning infants.

Figure 0.7. Experimental design used by Hochmann et al., (2011). Italian-learning 12-month-olds prefer the side predicted by the consonants (colored circles) rather than the side predicted by the vowels.

The studies described above found a consistent C-bias in French- and Italian-learning toddlers during the second year of life, using different paradigms such as the NBC task, familiar object-label recognition and unfamiliar object-word learning. These results were found in toddlers acquiring French and Italian, would they extend to other languages?

4.4. Cross-linguistic variation in the C-bias during the second year of life

Studies have also been conducted with English-learning toddlers but the presence of the C-bias is not as clear as with French- and Italian-learning toddlers. Following the results showing a sensitivity to mispronunciations occurring on the onset consonant of

familiar words as young as 14 months (Bailey & Plunkett, 2002; Ballem & Plunkett, 2005; Swingley & Aslin, 2000, 2002) and on medial consonant mispronunciations at 19 months (Swingley, 2003), Mani and Plunkett (2007) examined whether English-learning 15-, 18- and 24-month-olds are sensitive to vowel and consonant mispronunciations of familiar words to assess the relative weight of consonants and vowels in lexical recognition. As in Zesiger and Jöhr (2011), toddlers' word recognition was measured by their looking times to images corresponding to the auditorily presented familiar target words. These target words were either correctly pronounced or mispronounced (on the consonant or on the vowel). While one experiment showed that recognition of familiar words was more impaired with consonant mispronunciations than vowel mispronunciations, thus establishing a C-bias in familiar word recognition at 15 months of age, this finding could neither be replicated with older toddlers nor with younger ones (12-month-olds; see Mani & Plunkett, 2010). Interestingly, while studies on French observed a C-bias at 14 months (Zesiger & Jöhr, 2011) by showing that consonant mispronunciations were detected but not vowel mispronunciations, the absence of a C-bias in Mani and Plunkett (2007) at 18 and 24 months was shown by the detection of both consonant and vowel mispronunciations. Thus consonants and vowels would be equally well processed in English-learning toddlers whereas French-learning toddlers around the same age have difficulties processing vowels.

The lack of evidence for a C-bias with English-learning 12- (Mani & Plunkett, 2010), 18- and 24-month-old toddlers (Mani & Plunkett, 2007), might be due to methodological reasons. Indeed, in these experiments, toddlers were always presented with two images while the target word heard during the experiment corresponded to only one of the two images. Thus, the sensitivity to mispronunciations in Mani and Plunkett (2007, 2010) might have been contaminated by the degree of mismatch between the distractor label and the familiar target word. In order to avoid this potential confound, Mani, Mills, and Plunkett (2012) used an electrophysiological method, namely the ERPs, which allowed investigating subjects' sensitivity to the relationship between a heard label and the referent alone. Therefore, instead of giving two images (one distracter and one target), Mani and colleagues (2012) presented only one image. Results provided clear evidence that English-learning 14-month-olds are sensitive to vowel mispronunciations of familiar words (consonant mispronunciations were not investigated).

Moreover, the lack of evidence for a stable C-bias, through the second and third years of life in English, was also found with unfamiliar words. Indeed for new word learning in English toddlers, the C-bias was found at 30 months (Nazzi, Floccia, Moquet, & Butler, 2009) but not between 16 and 24 months (Floccia et al., 2014). In the latter study, toddlers were tested with the interactive learning task used in Havy and Nazzi (2009). Results showed that English-learning 16- and 24-month-olds succeeded both in the consonant and in the vowel condition, hence also suggesting no C-bias in learning new words during the second year of life.

Taken together with studies showing sensitivity to consonant mispronunciations (Stager & Werker, 1997; Yoshida, Fennell, Swingley, & Werker, 2009; Fennell & Werker, 2003), the studies investigating the emergence of the C-bias with English-learning toddlers did not provide evidence of a C-bias as consistently as shown in French- (Nazzi, 2005; Havy & Nazzi, 2009; Zesiger & Jöhr, 2011) and Italian-learning (Hochmann et al., 2011) toddlers.

What about languages that do not follow the same trend of having more consonants than vowels? Højen and Nazzi (in revision) provide a first piece of information regarding Danish. Danish is considered to be one of the rare languages possessing more vowels than consonants (Bleses, Basbøll, & Vach, 2011). It also has consonant reduction phenomena, making the vowels even more salient than in other languages. Using the same paradigm as in Havy and Nazzi (2009), Højen and Nazzi (in revision) tested Danish-learning 20-month-old toddlers. Results reveal a pattern opposite to French-learning 20-month-olds (Nazzi, 2005): Danish-learning toddlers were found to succeed in learning object-label pairings when words were contrasted in vowels but not when they were contrasted in consonants. Hence, this study provides evidence of a vowel bias (V-bias) in Danish, using a lexically-related task. Therefore, the C-bias observed so far during the second year of life in English (at 15 months only; Mani & Plunkett, 2007; after 30 months in Nazzi et al., 2009a), Italian (Hochmann et al., 2011) and French (Havy & Nazzi, 2009; Nazzi, 2005; Zesiger & Jöhr, 2011) may be reversed in some languages, possibly in relation to consonant/vowel ratios, phonological or lexical properties that will need to be specified in future studies.

Although the previous studies differed in terms of types of words (familiar and unfamiliar), languages (French, English, Danish, Italian) and methods (mostly IPL and interactive learning tasks), observing cross-linguistic variation in the appearance of the

C-bias during the second year of life poses the question of its origin. Is it cross-linguistically present from birth as suggested by Nespor et al. (2003), who proposed a language-general initial bias? If so, how do we account for the bias reversal in Danish-learning toddlers? And how can we explain that the C-bias in English-learning toddlers is present at 15 months (Mani & Plunkett, 2007) but not at 12 months (Mani & Plunkett, 2010)? The next section describes three different hypotheses that have been proposed to explain the origin of the C-bias.

4.5. Origin of the C-bias: three hypotheses

Initially, Nespor et al. (2003) hypothesized that consonants would have a dominant role compared to vowels in lexical processing and proposed the “initial bias” hypothesis: the C-bias would be present at birth, thus would be observed in newborns. According to this hypothesis, due to their intrinsic characteristics (greater distinctiveness and informativeness), distinguishing between lexical items would be the work of consonants more than that of vowels. Moreover, because these intrinsic characteristics are language-general and because most of the languages have more consonants than vowels, the initial bias hypothesis proposes that the C-bias would be present cross-linguistically. To support this hypothesis, Bonatti et al. (2005) found evidence of a C-bias in French-speaking adults. Since French is a rather well-balanced language in the number of consonants and vowels (17 consonants and 15-16 vowels, see Peereman & Dufour, 2003), Bonatti et al. (2005) explained their findings (ability to track regularities between consonants rather than between vowels to retrieve words) by the fact that subjects initially encode consonants as word identification mediators.

In contrast, Keidel, Jenison, Kluender, and Seidenberg (2007) suggested that the C-bias would be learned from sophisticated analyses on one’s native language lexicon from which consonants higher informativeness (compared to vowels) would emerge. To bring support to this “lexical bias” hypothesis, Keidel et al. (2007) analyzed 4943 French CVCVCV words (based on Lexique 3; New, Pallier, Ferrand, & Matos, 2001). Among these selected words, there were 820 unique three-consonant tiers and 562 unique three-vowel tiers. Averaging the number of each type of tiers on the 4943 words shows that each consonant tier appears in 6.03 words whereas each vowel tier appears in 8.8 words. Therefore, consonants may be more numerous than vowels but consonant tiers are

statistically less heard than vowel tiers. Moreover, in a second analysis using Shannon (1948) information theory, Keidel et al. (2007) showed that consonants yield higher informative scores than vowels. These statistical analyses do not show that the initial bias hypothesis (Nespor et al., 2003) is incorrect but provide an alternative on how consonants might become more informative than vowels through experience with the structure of the lexicon, and later lead to a C-bias in processing words.

According to the lexical bias hypothesis, biases (C- and V-bias) that shape word processing would not be present at birth and would emerge later in development when toddlers have a sizeable lexicon from which they learn that consonants or vowels are more informative in lexical processing. Moreover, since the structure of the lexicons is likely to vary across languages, the lexical bias hypothesis would predict cross-linguistic differences. Thus, languages like French or English would lead to a C-bias because of the lexically greater informativeness of consonants. In contrast, languages like Danish might lead to a V-bias in processing words, if vowels in the Danish lexicon are proven to be more informative than consonants. Further cross-linguistic analyses will be needed to explore consonants and vowels respective informativeness in the lexicon of various languages.

The third hypothesis concerning the origin of the C-bias was proposed by Floccia, Nazzi, Delle Luche, Poltrock, and Goslin (2014) and Bouchon et al. (in press). These authors proposed a learned C-bias hypothesis based on the acoustic/phonetic level. The acquisition of the C-bias would be due to the fact that there are acoustic/phonetic differences between consonants and vowels: consonants tend to be shorter, less stable and more distinctive (Eimas et al., 1971; Ladefoged, 2001; Repp, 1984) than vowels. These differences would lead to the construction of two phonologically distinct categories that differ in their relevance for lexical processing. Infants, through acoustic/phonetic experience to their native language would learn these differences and a functional asymmetry would emerge, consonants being given more weight to process words, and vowels more weight to process prosody and syntax. Knowing that the native vowel inventory starts being acquired around 6 months and the native consonant inventory starts to be acquired around 10 months of age, the C-bias would emerge during the first year of life, before infants possess a sizeable lexicon. Furthermore, due to acoustic/phonetic differences across languages, the emergence of this C-bias is predicted to vary depending on the language in acquisition, and leave open the possibility that infants would develop a C-bias, a V-bias or no bias, as a function of the phonetic properties

of their native language (e.g., C/V ratio, use of vocalic and/or consonantal reduction, presence of short-long phonemic contrasts).

To sum up (Table 0.1.), if the initial bias hypothesis (Nespor et al., 2003) is correct, the C-bias should be observable at birth cross-linguistically, independently of the acoustic/phonological or lexical properties of the language to be acquired. If the lexical bias hypothesis is correct, the C-bias would be observable after toddlers have started acquiring a large enough lexicon. Although some studies provided evidence of familiar word recognition (Bergelson & Swingley, 2012; Tincoff & Jusczyk, 1999, 2012) around 6 months of age, infants do not have a sizeable lexicon before 12 months of age. Given the statistical nature of the learning processes proposed by Keidel et al. (2007) giving rise to the C-bias, the C-bias would emerge after 12 months of age and would depend on the language in acquisition. If the acoustic/phonetic bias hypothesis (Floccia et al., 2014; Bouchon et al., in press) is correct, the C-bias would emerge during the first year of life, before infants acquire a sizeable lexicon, and there would be developmental differences across languages.

These hypotheses propose different developmental trajectories to explain the emergence of the C-bias and only the two learned hypotheses predict cross-linguistic differences. Thus, the cross-linguistic variation found in the toddlers studies is more compatible with these learned hypotheses. However, since data were collected only after 12 months of age, it is unclear whether variation would be present at younger ages. Hence, it remains possible that an initial C-bias would be modulated by language acquisition in the first year of life. Therefore, the best way to further investigate the C-bias is to conduct developmental cross-linguistic studies in infants during the first year of life.

Table 0.1. Three different hypotheses for the emergence and the origin of the C-bias.

Hypotheses	Origin	When?	Cross-linguistic differences?
Initial	Innate	At birth	No
Lexical	Learned through lexical experience	Around 12 months	Yes (differences from the lexicon)

Acoustic Phonological	Learned through phonological experience	Before 12 months	Yes (differences from the phonology)
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4.6. How early is the C-bias present? The case of known word recognition in French

The original initial bias hypothesis (Nespor et al., 2003) proposes that the C-bias is cross-linguistically present at birth. To determine whether this hypothesis is correct, French offers a good opportunity to investigate the C-bias in the first year of life, given that the C-bias is so consistently found from 16 months to adulthood.

Knowing that infants have already stored some words at 11 months of age (Hallé & de Boysson-Bardies, 1994), Hallé and de Boysson-Bardies (1996) provided the first piece of evidence on how infants represent familiar words by testing French-learning 11-month-olds. The aim in this study was to determine what type of mental representations infants use to encode familiar words. Accordingly, using HPP, Hallé and de Boysson-Bardies (1996) investigated the question of infants' lexical representation by altering the initial or the medial consonant of French bisyllabic words. Infants were presented with lists of altered familiar words versus rare words. When the alteration occurred on the initial consonant, infants looked significantly longer to the altered familiar word list, whereas when the mispronunciation occurred on the medial consonant, no preference was shown. This indicated that there was apparent word recognition when the initial consonant was mispronounced but not when the medial consonant was mispronounced. These results suggest that in some cases, infants will respond to a familiar word even when not correctly pronounced and that this effect depends on the position in which the mispronunciation occurs. The authors proposed that at 11 months of age, word representations are not fully specified, thus explaining that some phonetic changes remain undetected. However, Vihman, Nakai, DePaolis, and Hallé (2004) reanalyzed Hallé and de Boysson-Bardies (1996) data in medial consonant mispronunciation by dividing the listening times into early and later trials. Doing this, Vihman et al. (2004) found that in the early trials, French-learning infants appear to recognize the familiar words whereas in the later trials, this effect vanished (Figure 0.8. B). This finding suggests that in early trials, infants "accepted" the familiar word mispronounced on the medial consonant as a

good exemplar of the familiar word but in the later trials, they appear to have detected the mispronunciation. What about vowel mispronunciations?

Figure 0.8. Reanalysis of Hallé and de Boysson-Bardies (1996) by Vihman et al. (2004). Mean listening time per trial (s) to familiar and rare words.

Following Hallé and de Boysson-Bardies (1994, 1996) showing a preference for familiar words over rare words in French-learning 11-month-olds but not if consonantly mispronounced, Poltrock and Nazzi (in revision) explored whether a different pattern would emerge if vowels were to be changed. More precisely, they asked whether French-learning 11-month-olds are equally sensitive to consonant and vowel mispronunciations of familiar words. In a first baseline experiment, infants were presented with familiar words and pseudo-words (e.g., /gato/ [cake] vs. /gali/), and preferred to listen to the familiar words compared to the pseudo-words. Knowing that infants would show a familiarity effect (as previously found by Hallé & de Boysson-Bardies, 1994 for French; Vihman et al., 2004 for English; Swingley, 2005 for Dutch) Poltrock and Nazzi conducted a second experiment in which infants were presented with both consonant and vowel mispronunciations of the familiar words used in the first experiment (e.g., /gapo/ vs. /gatø/). Eleven-month-old infants preferred to listen to the vowel mispronunciations compared to the consonant mispronunciations, suggesting that they considered the vowel mispronunciations as more similar to the familiar words than the consonant mispronunciations. Thus at 11 months, infants already rely more on consonants than vowels to recognize familiar words. This is the first time that the C-bias is found this early in French (or in any other language).

To further investigate the emergence of the C-bias, Bouchon et al. (in press) tested French-learning 5-month-olds on the recognition of their own name. In a first, main set of experiments, infants were presented with repetitions of their own names either correctly pronounced or mispronounced. In the consonant condition, infants were presented with their names correctly pronounced and their names mispronounced on its initial consonant (e.g., /feliks/ *Félix* vs. /veliks/). In the vowel condition, infants heard their names correctly pronounced and their names mispronounced on the initial vowel (e.g., /ygo/ *Hugo* vs. /ugo/). In the consonant condition, infants listened equally to the correctly pronounced name and the consonant mispronunciations, whereas in the vowel condition,

they listened significantly longer to the correctly pronounced names compared to the vowel mispronunciations. This pattern thus suggests that infants considered the consonant mispronunciations as good exemplars of their own names, but the vowel mispronunciations as different from their own names. This suggests greater reliance on vowels than on consonants. To rule out possible effects of pure acoustic preferences, a first group of infants was presented with the stimuli used in the main experiments (e.g., infant Martin heard *Victor* vs. *Zictor*). Results for the yoked control infants showed that infants listened equally to correct and mispronounced names, hence ruling out this alternative explanation. Hence, Bouchon et al. (in press), contrary to all other studies in French showing a C-bias (e.g., Zesiger & Jöhr, 2011; Havy & Nazzi, 2009; Nazzi, 2005; Poltrock & Nazzi, in revision), provide evidence of a vowel bias (V-bias) in a name recognition task at 5 months. Therefore, these findings do not support the initial bias hypothesis (Nespor et al., 2003).

Taken together, the findings by Poltrock and Nazzi (in revision) and Bouchon et al. (in press) suggest that the C-bias appears during the first year of life in French. However, one limitation of this conclusion is that these two studies used different types of words: names at 5 months (Bouchon et al., in press) and familiar words at 11 months (Poltrock & Nazzi, in revision). Knowing that names are possibly produced with higher prosodic variation than familiar words, by more speakers and in more contexts, vowels contained in names might have been produced with acoustically more variable information (since prosodic information is mainly carried by vowels). Therefore, the increased vowel sensitivity in Bouchon et al. (in press) at 5 months could be due to this difference in stimuli. The difference in biases between Poltrock and Nazzi (in revision) and Bouchon et al. (in press) would be an artefact of having used different stimuli.

4.7. Research goal (1)

Following Bouchon et al. (in press) and Poltrock and Nazzi (in revision) findings, we investigated the emergence of the C-bias in French-learning 6- and 8-month-olds in a segmentation task. More precisely, in a series of 4 experiments (presented in Experimental Chapter 2), we explored whether consonant and vowel mispronunciations of target words segmented from fluent speech are considered or not as the target words. Our series of experiments differ in two ways compared to Bouchon et al. (in press) and

Poltrock and Nazzi (in revision). First, these two latter studies used a task in which infants had to recognize words that have already been stored in memory. In our series of experiments, infants first have to segment unknown target words heard in passages and then recognize these segmented word forms that are either correctly or mispronounced (on the consonant or on the vowel). This segmentation paradigm thus presents infants with a supplementary level of difficulty by adding a segmentation process along with the recognition process, allowing us to explore the C-bias at a different level of processing. Second, this procedure allows us to observe whether the C-bias would influence recognition of words that have just been segmented, hence allows us to investigate the C-bias impact on words that have no meanings yet, contrary to the words used in Poltrock and Nazzi (in revision) and Bouchon et al. (in press). Since we use word segmentation as a tool to investigate the emergence of the C-bias in French-learning infants, in the next section, we present a review of the literature on word segmentation abilities in (adults and) infants, and that will highlight the cues that infants use to segment continuous speech.

5. Word segmentation

Figure 0.9. Speech signal presents no apparent word boundaries. Segmentation procedure with Praat at the phonemic (tier 1), syllabic (tier 2) and word (tier 3) levels. Retrieved from the University of Geneva website:
(<http://latlcui.unige.ch/phonetique/easyalign.php>)

In our everyday life, we are exposed to continuous speech. At first glance, understanding speech seems easy and extracting words from sentences is not done consciously or with a lot of cognitive effort. However, as soon as we are confronted to a foreign language, spotting words and word boundaries is not trivial as they are not apparent (as illustrated in Figure 0.9.). The same goes for infants learning their native language. Since words are rarely produced in isolation (Brent & Siskind, 2001) and since speech directed to infants between 6 and 9 months contains only 7% of isolated utterances (van de Weijer, 1998), infants will have to detect word boundaries in order to extract word forms and attach these sound patterns to their corresponding meanings. Moreover, Woodward and Aslin (1990) showed that even when asked to teach new words

to their 1-year-old toddlers, mothers do not tend to produce these words in isolation. Therefore, segmentation abilities are crucial for infants to learn words.

Furthermore, several findings showed links between the early ability to segment speech and later linguistic competence (Graf Estes et al., 2007; Newman et al., 2006). Among these studies, Kooijman et al. (2013) investigated the possible link between segmentation proficiency and later language skills. Using ERPs in the first part of their study, they tested Dutch-learning 7-month-olds to determine whether infants are able to segment words at that age. Results showed that 7-month-olds present an ERP signature of segmentation suggesting successful segmentation. However, the results revealed two subgroups of infants: infants showed either a positive-going or a negative-going response. The literature on infant ERPs shows that responses are likely to vary as a function of age. Moreover, several studies showed that early responses can emerge with different polarity from responses later in life: for example, a positive-going response in young infants can change into a negative-going response in older infants (Männel & Friederici, 2010; Garcia-Sierra, Rivera-Gaxiola, Percaccio, Conboy, Romo, Klarman, Ortiz & Kuhl, 2011). Given these studies showing a developmental change in the polarity of responses, Kooijman et al. (2013) interpreted the positive-going responses as a signature of a less mature segmentation signature while the negative-going responses suggests a more mature pattern. Furthermore, the negative-going response obtained at 7 months in Dutch-learning infants was also observed in older infants (Kooijman et al., 2009 with Dutch-learning 10-month-olds). In a second part of the study, Kooijman et al. (2013) evaluated the same infants at 3 years of age on vocabulary comprehension and word and sentence production. Results showed that at 3 years, infants who had a negative-going response at 7 months outperformed infants who had a positive-going response. Thus, infants who had a more mature segmentation signature had better performance at 3 years of age. Therefore, infants' early ability to segment speech appears to be a good predictor of how they will comprehend and produce words a few years later.

Knowing that segmentation abilities are prerequisites to learn words and appear to predict later language development, many studies investigated early segmentation abilities in infancy. Experimental Chapter 1 contributes to this line of research: it explores how French-learning infants start segmenting speech during the first year of life and how. To answer these questions, we will present two series of experiments conducted in French-learning 6- and 8-month-olds. Because supporting the rhythmic bootstrapping

hypothesis (Nazzi et al., 2006) was our ultimate goal, the first series of experiments investigated the role of rhythmic units along with transitional probabilities (TPs), while the second series explored how early French-learning infants can segment speech, using their native rhythmic units. Since TPs and rhythmic units have been proposed as crucial at the onset of segmentation, they have received the most attention in infant studies. Thus, following this trend, in the two next sections, we first present studies establishing an early use of TPs and rhythmic units and then we present other cues that also help infants segmenting continuous speech.

5.1. Transitional probabilities

Transitional probabilities (TPs) correspond to distributional cues informing about the probability that a pair of events XY will occur. The transitional probability of Y given X is computed as follows: $(TP = P(Y|X) = \frac{frequency(XY)}{frequency(X)})$. A high TP indicates that X strongly predicts that Y will occur while a low TP indicates a weaker contingency between X and Y. Thus, TPs can inform about the probability that two syllables are within the same word or not and subsequently can cue word boundaries.

To investigate the role of TPs in segmenting words, Saffran et al. (1996a) evaluated English-speaking adults. They exposed them to an artificial language in which the only available cue to segment words was the transitional probabilities between syllables. Stimuli consisted in four consonants and three vowels used to make an inventory of 12 CV syllables. The syllables were then combined to form six target trisyllabic words (e.g., *pidabu*, *dutaba*) and six controls which consisted of a syllable pair from a target word, plus an additional syllable (e.g., *pidata*, *bitaba*). For familiarization, target word tokens were concatenated in a random order to form streams that contained no pauses. After a 21 minute-long exposure to the artificial streams, adults were presented with trials containing both target and control words and had to determine which had been present in the streams. While the target words respected the TPs of the familiarized streams, the control words violated the TPs to which participants were familiarized with. Subjects' performance showed that overall they succeeded in recognizing the target words. Furthermore their performance could be enhanced when prosodic cues were added to the TPs. This finding indicates that adults are able to segment and learn artificial words by tracking TP information between syllables and additional prosodic cues.

Saffran, Aslin, and Newport (1996b) further explored the role of TPs in speech segmentation during development, testing English-learning 8-month-olds. In this study, infants were familiarized with a 2 minute-long artificial stream consisting of four alternating three-syllable non-words. The only available cues to word boundaries were TPs which were higher within than between words. At test, infants were exposed to repetitions of three-syllable words that either followed the familiarized TP pattern or not. Infants' mean listening times to each type of words was measured using HPP. Results showed that infants listened longer to the words following a novel TP pattern compared to the words following the familiar TP pattern, suggesting a discrimination between the two different TP patterns. Thus, English-learning 8-month-olds are able to extract words from continuous stream solely on the basis of TPs.

Similar results were obtained later, further showing that IDS facilitates using TPs to segment (Thiessen, Hill, & Saffran, 2005) between 6.5 and 8.5 months and showing that other cues can be used along with TPs (Curtin, Mintz, & Christiansen, 2005; Thiessen & Saffran, 2003). However, all of these studies used artificial languages in which prosody and coarticulation are not as salient as in natural speech, hence possibly making the TPs more reliable to extract words from speech streams. Pelucchi, Hay, and Saffran (2009) tested English-learning 8-month-olds to observe whether they are able to show segmentation abilities with TPs in a natural language. Thus, in this study, English-learning 8-month-old infants were exposed to Italian speech. Although Italian and English share the same strong-weak stress pattern at the lexical level (Mancini & Voghera, 1994; Cutler & Carter, 1987), many other cues (e.g., allophonic and phonotactic cues) are quite different. Thus, testing English-learning infants with Italian speech is a good way to investigate infants' use of TPs in a word segmentation paradigm in which the stimuli are new to infants, thus making other cues irrelevant to segment. Infants were familiarized with Italian sentences and subsequently tested on familiar words (heard during the familiarization) versus novel words (not heard during the familiarization). Moreover, the words that had to be segmented were salient in terms of TPs. For example, the familiarized words *fuga* and *melo* each appeared 6 times in the sentences and the novel words *pane* and *tema* never occurred; however, *pa*, *ne*, *te* and *ma* appeared in the sentences but never next to each other, rendering the TPs *pa-ne* and *te-ma* null. Results showed that 8-month-olds listened longer to the target words compared to the novel ones, suggesting that they could segment the target words. However, this finding shows that

infants are sensitive to the familiarity of sequences (those with high TPs). To further investigate whether infants track statistical regularities, in another experiment, Pelucchi et al. (2009) manipulated the level of TPs (high vs. low TPs), and demonstrated that infants were successfully discriminating high and low TP sequences. These findings thus established that 8-month-olds can track TPs to help the segmentation process.

Further studies were conducted in languages other than English and also showed evidence of subjects' sensitivity to TPs in adults (French: Mersad & Nazzi, 2011) and infants (French: Mersad & Nazzi, 2012; Dutch: Johnson & Tyler, 2010), but also report some limits in the use of TPs: while Mersad and Nazzi (2012) showed that TPs could be used only when supported frequent words such as *Mommy* at 8 months, Johnson and Tyler (2010) showed that 5.5- and 8-month-old infants could use TPs only when words were of uniform length.

5.2. Rhythmic units

The idea of different rhythmic classes among languages goes back many years (Abercrombie, 1967; Pike, 1945) and received linguistic evidence in the 90's (Arvaniti, 1994; den Os, 1988; Fant, Kruckenberg, & Nord, 1991; Nazzi, 1997; Ramus, Nespor, & Mehler, 1999; Shafer, Shucard, & Jaeger, 1999). These rhythmic classes are also supported by the differences in the way adults segment continuous speech. Indeed, the syllable appeared as the segmentation unit used by adults speaking French (Mehler, Dommergues, Frauenfelder, & Segui, 1981; Peretz, Lussier, & Béland, 1998), Spanish and Catalan (Sebastian-Gallés, Dupoux, Segui, & Mehler, 1992) whereas the trochaic unit appeared to be used by English (Cutler et al., 1986; Cutler & Norris, 1988; McQueen et al., 1994) and Dutch (Vroomen, van Zon, & de Gelder, 1996) speakers.

Nazzi et al. (2006) proposed the early *rhythmic segmentation* hypothesis (rhythmic bootstrapping), according to which the rhythmic unit of the native language would drive early segmentation. Therefore, segmentation would be syllable-based in French, and stress-based in English. Therefore, the cues that would allow infants to segment speech would be the rhythmic units of their native language.

5.2.2. *Trochaic units in stress-based languages*

Following Jusczyk and Aslin (1995) result showing a segmentation effect at 7.5 months in English-learning infants, Jusczyk, Houston, and Newsome (1999a) extended that study to bisyllabic words. Using HPP, infants' segmentation abilities were assessed with bisyllabic words following either a trochaic (first syllable accentuated – strong-weak) or an iambic (second syllable accentuated – weak-strong) pattern. Infants were tested at two different ages: 7.5 and 10.5 months. Results showed that while 10.5-month-olds were able to segment both trochaic and iambic words, 7.5-month-olds were only able to segment trochaic words. These findings support the proposal that English-learning infants first segment speech on the basis of trochaic units which is the most frequent in their native language. Then, they need additional few months of exposure to speech to become able to segment the less frequent iambic units, using other segmentation cues.

To investigate whether Dutch-learning infants follow the same developmental pattern to segment trochaic and iambic bisyllabic words, and knowing that Kooijman, Hagoort, and Cutler (2005) found a specific neural pattern of trochaic bisyllabic word segmentation, Kooijman et al. (2009) used ERPs. In this study, Dutch-learning 10-month-olds were familiarized with tokens of isolated iambic bisyllabic words (e.g., *geTIJ*). Then, the test phase consisted of passages, either containing the familiar word (e.g., *geTIJ*) and an unfamiliar (e.g., *meGEEL*) iambic word, or trochaic words with the familiar syllable (e.g., *TIJger*) or an unfamiliar (e.g., *GEler*) strong syllable. Results showed that Dutch-learning 10-month-olds were able to segment the iambic familiar words. However, the familiarity response obtained time locked with the strong syllable of the iambic word was similar to the response obtained for strong syllables in trochaic bisyllabic words at the same age (Kooijman et al., 2005). Taken together, these findings suggest that Dutch-learning 10-month-olds still rely strongly to trochaic units even when segmenting iambic bisyllabic words, thus establishing trochaic-unit-based segmentation in Dutch-learning infants, suggesting a prior use of trochaic units which is in line with English-learning infants' segmentation data (Jusczyk et al., 1999a).

Taken together, the studies conducted in English and Dutch have shown a clear advantage of trochaic units in segmenting speech, hence supporting the rhythmic bootstrapping hypothesis (Nazzi et al., 2006) for stress-based languages.

5.2.3. Syllabic units in syllable-based languages

At first, French-learning infants were found to present a lag in the emergence of bisyllabic segmentation capacities. Indeed, Gout (2001) carried out segmentation experiments, implementing Jusczyk and Aslin (1995) and Jusczyk et al. (1999a) designs in French-learning infants. 7.5-month-old infants were familiarized with words and then tested on passages. At that age, infants were able to segment monosyllabic CVC words, but interestingly, they were not able to segment bisyllabic words (either “simple” CVCVC and CVCV or “complex” CCVCCV and CCVCV) as the English-learning infants at the same age. This initially unexpected result could however be due to the difference in rhythmic units between English and French. If the rhythmic bootstrapping hypothesis is correct, then segmenting bisyllabic words should be more difficult for French-learning infants than English-learning infants (for whom segmentation of bisyllabic words would be driven by trochaic units rather than syllables) as it is more difficult for English-learning infants to segment iambic than trochaic units.

Following these results, Nazzi et al. (2006) investigated the role of the syllable in French speech segmentation. To test the prediction of the syllable being the rhythmic segmentation unit in French, they tested French-learning infants at 8, 12 and 16 months of age. The rationale was that if French infants use the syllable as a segmentation unit, they should place boundaries between every two consecutive syllables, extracting both syllables of a bisyllabic word as independent units, rather than extracting the whole bisyllabic word. In the first experiment, as in Jusczyk et al. (1999a), infants were familiarized with repetitions of bisyllabic words (e.g., /pytwa/ and /tukã/) and tested on passages containing or not the target words. No significant segmentation effect was found at 8 and 12 months. Only 16-month-olds were able to extract whole bisyllabic words (infants then listening longer to the passages containing the target words). In other experiments, infants were familiarized with repetitions of the final or initial syllables of the bisyllabic words (e.g., /twa/ and /kã/ for final syllables; /py/ and /tu/ for initial syllables) and then tested on passages containing or not the bisyllabic words containing the target syllables (e.g., /pytwa/ and /tukã/). No segmentation was observed at 8 months of age. At 12 months, infants segmented both the initial and final syllables that belonged to the bisyllabic words but failed to segment the bisyllabic words as whole units. Interestingly, at 16 months, while infants succeeded to segment bisyllabic words as whole units, they failed to segment the final syllables of the target words.

These developmental data support the proposal that the syllable is the segmentation unit in French and further demonstrate that French-learning infants initially segment speech into syllable-sized units. Indeed, from no segmentation effect at 8 months (neither syllabic nor bisyllabic segmentation), to syllable extraction at 12 months, French-learning infants ultimately segment whole bisyllabic words at 16 months. This study is the first to have found support for the rhythmic segmentation hypothesis in French. However, it was rather unexpected that French-learning 8-month-olds were not able to extract syllabic units while English 7.5-month-olds are able to extract their native trochaic units (Jusczyk & Aslin, 1995; Jusczyk et al., 1999a). The absence of syllabic segmentation of bisyllabic words in French was taken as a developmental lag in French or, rather as an advantage of the trochaic unit over the syllabic unit in segmentation. Even though French-learning infants could segment monosyllabic words as soon as 7.5 months (Gout, 2001) as English-learning infants (Jusczyk & Aslin, 1995; Jusczyk et al., 1999a), few months were needed to discover that this lack of results in French-learning infants was partly due to methodological reasons that might have influenced infants' combined use of multiple segmentation cues.

5.3. Other cues

5.3.1. Allophonic variations

Allophonic variations correspond to the fact that some phonemes are pronounced differently depending on their position within a word (edge or nucleus – e.g., /t/ in *nitrate* and *night rate* are differently realized – Hohne & Jusczyk, 1994). Thus, depending on how a phoneme is realized, allophonic variations can provide a cue about word boundaries. Jusczyk, Hohne, and Bauman (1999b) investigated the role of allophonic variations in segmentation. In their study, using HPP, English-learning infants were presented with 2 two-syllable targets and then tested on their ability to recognize these targets in phrasal contexts. In a first experiment, infants were presented with two targets (either *night rates* – *doctor* or *nitrates* – *hamlet*) and then tested on 2 passages containing the targets and 2 passages containing control words. For example, infants familiarized with *nitrates* heard the passage containing *night rates* (control passage) and the passage containing *nitrates* (target passage). The rationale was that if infants can use allophonic variations to segment words, they should listen more to the passages containing the target compared to the

passage containing the target allophonic variant (e.g., infants familiarized with *nitrates* should listen longer to the passage containing *nitrates* than to the passage containing *night rates*). Results showed that at 9 months, English-learning infants listened equally to the target and target allophonic variant passages, suggesting that they could not detect or use the difference between these allophonic variants. However, at 10.5 months, infants listened longer to the target passage compared to the target allophonic variant passage, suggesting that they discriminated the two allophonic variants. These findings indicate that although infants are sensitive to allophones at 2 months of age (Hohne & Jusczyk, 1994), they cannot use allophonic variations within a word to segment words at 9 months. By 10.5 months, English-learning infants have become able to use allophonic variations to their advantage to segment speech. This finding thus provides further insights on how segmentation skills develop.

5.3.2. Phonotactic regularities

Phonotactic regularities are related to constraints on authorized sound sequences at the lexical level. For example, in English, while the phonemic sequence /st/ is allowed (e.g., *straw*, *stripe*, *street*), the sequence /zt/ is not allowed within the same word. English adults can spot a word boundary when hearing an “illegal” sequence such as /zt/ and determine that /z/ is part of the end of one word and /t/ is the beginning of the following word. Infants were also found to become sensitive to phonotactic regularities of their native language between 6 and 9 months of age (Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993b). To investigate the role of phonotactic regularities in early segmentation, Mattys, Jusczyk, Luce, and Morgan (1999) used HPP to evaluate English-learning 9-month-olds on their preference between two-syllable CVC.CVC words. These words differed with respect to the phonotactic level of their cross-syllabic C.C clusters. This resulted in two types of phonotactic patterns: the clusters either had a low probability or a high probability of occurrence within words in English. Results showed that English-learning 9-month-olds preferred the words that were following a cluster that had a high probability of occurrence. Thus, this finding demonstrates that 9-month-olds are sensitive to how phonotactic regularities typically align with word boundaries. Similar results were obtained in English-learning infants at the same age (Mattys & Jusczyk, 2001a) with informative phonotactic regularities occurring either at the end or beginning of the word that had to be segmented and French-learning 10- and 13-month-old infants

(Gonzalez-Gomez & Nazzi, 2013) where infants at both ages were able to extract words following frequent phonotactic structures but only the older infants were able to segment words following infrequent phonotactic structures.

5.3.3. Known words

The youngest infants in whom segmentation could be observed were 6 months of age in English. However, this evidence was obtained in particular conditions. In Bortfeld et al. (2005) study, using HPP, English-learning 6-month-olds were familiarized with two types of passages: one in which the target word was always preceded by a familiar word (either *Mommy* or infants' own name) and the other in which the target word was always preceded by the same unfamiliar word. At test, infants recognized the word that was preceded by the familiar word but not the word that followed the unfamiliar word. This finding thus suggests that infants can use knowledge of familiar word forms to segment continuous speech. Note that similar findings were observed with French-learning 8-month-olds (Mersad & Nazzi, 2012; *Maman* [Mommy] helps segmenting monosyllabic words).

5.3.4. Edge alignment

Recently, Johnson et al. (2014) carried out segmentation experiments with English-learning 6-month-olds. They were familiarized with passages containing target words located either in sentence-medial position or at the edges of the sentences. Only those infants familiarized with passages containing target words aligned with edges exhibited recognition of the target words. This result is also in line with Seidl & Johnson (2006) study with older infants (8 months), showing a facilitating effect of edge alignment in word segmentation. Thus, position inside a sentence can also be a crucial factor to help infants retrieving word forms inside speech streams.

5.3.5. Infant-Directed Speech

Finally, one largely discussed factor in psycholinguistic is the use of Infant-Directed Speech (IDS) versus Adult-Directed Speech (ADS). Singh, Nestor, Parikh, and Yull (2009) explored whether IDS can facilitate word learning in English-learning 7- and 8-month-old infants. In this study, infants were familiarized with repetitions of two words: one

produced in IDS and the other in ADS. They were then tested 24 hours later on the familiarized words recognition in sentential context. Half of the infants were evaluated on 2 passages produced in IDS and the other half on passages produced in ADS. In each condition (IDS vs. ADS) while one passage contained the target word which infants were familiarized with, the other contained a novel word that was not heard during familiarization. Results showed that infants listened longer to passages containing the target words produced in IDS whether they were presented within IDS or ADS passages. Thus, Singh et al. (2009) determined that IDS helps infants to store their first word forms at 9 months of age. Note that this IDS facilitation was also found when infants were tested immediately after familiarization (Singh et al., 2008; Thiessen, Hill, & Saffran, 2005), suggesting that in addition of helping infants memorizing word forms, it also helps infants in early segmentation. This facilitation could be due to the fact that IDS consists of a number of attention-getting characteristics such as pitch variation, increased amplitude, slower speech rate, and lengthened syllables.

5.4. Cue interaction

As mentioned above, many cues are available to infants in order to successfully extract their first word forms. However, the age at which segmentation abilities appear to emerge is not always the same cross-linguistically. This is partly due to the fact that infants combine these cues, and depending on their developmental level and whether infants are proficient to use particular cues, this combination might hinder or enhance infants' early segmentation abilities.

For example, while Johnson and Tyler (2010) showed that when 8-month-old infants are presented with artificial languages with reliable TPs between syllables but made up of words with and varying length (2 or 3 syllables), they fail to show segmentation effects, Mersad and Nazzi (2012) showed that when familiar words signal word boundaries along with TPs, 8-month-olds do show segmentation effects for languages with varying word lengths. Therefore, TPs appear to combine with other segmentation cues in infant studies, suggesting that, early on, infants segment continuous speech by combining different cues, so that successful segmentation will depend on how well infants combine those cues.

Another example is provided by Jusczyk et al. (1999b). In this study, while 9-month-old infants could not extract targets solely on the basis of allophonic cues, they succeeded when relevant TPs were added. Infants succeeded in combining these two cues at the age of 10 months, suggesting that sufficient developmental advancement is needed to successfully combine transitional probabilities and allophonic variations.

Lastly, methodological factors might lead infants to successful or unsuccessful combination of multiple segmentation cues. This might be the case for presentation order (whether familiarizing with words and testing with passages or familiarizing with passages and testing with words) in studies using HPP. Recently, Nazzi et al. (2014) revisited bisyllabic word segmentation in French-learning infants, testing them with both orders of presentation (word-passage and passage-word). With the word-passage order, French-learning infants were not able to segment bisyllabic words as in Nazzi et al. (2006). However, when presented with the passage-word order, 8-month-olds were able to segment bisyllabic words, pushing down to 8 months the age of bisyllabic segmentation when Nazzi et al. (2006) only found that effect in 16-month-olds (Figure 0.10.).

Due to different listening times to sentences between the word-passage and passage-word orders, the difference observed in segmentation effects in French-learning infants could have emerged from differences in access to TPs. Indeed, while infants have progressively access to TPs during the test phase in the word-passage order, infants, in the passage-word order, have already calculated TPs during familiarization and thus could use them right from the beginning of the test phase.

Figure 0.10. Presentation order leads to different results in the Headturn Preference Procedure. Mean orientation times (s) to target and control words in Word-Passage (left panel) and Passage-Word (right panel) orders. Figure made of Nazzi et al. (2014) Experiments 1 (left panel) & 2 (right panel) data. * stands for $p < .05$.

6. Goals of the present dissertation

To sum up, we present in Table 0.2. a summary of the earliest evidence of segmentation effects found across languages.

In Experimental Chapter 1, we will present a series of segmentation experiments conducted in French-learning 6- and 8-month-olds (Goyet, Nishibayashi, & Nazzi, 2013; Nishibayashi, Goyet, & Nazzi, in press) taking into account the crucial factors such as presentation order and TPs to facilitate the observation of segmentation effects. The aim of this chapter is to explore the early role of syllabic units in segmenting speech in French, further testing the rhythmic segmentation hypothesis (Nazzi et al., 2006). Thus, we conducted 8 experiments to answer the following questions: 1) When does the segmentation ability appear in French-learning infants? 2) Is the syllabic unit the rhythmic segmentation unit in French? 3) What is the role of gestational maturation versus postnatal experience in the use of the syllabic units to segment speech?

Table 0.2. Earliest evidence of segmentation across languages.

Authors	Language	Earliest age of segmentation	Type of word	Order
Gout, 2001	French	8 months	Monosyllabic	Word-Passage
Nazzi et al., 2014	French	8 months	Bisyllabic	Passage-Word
Bosch et al., 2013	Spanish & Catalan	6 months	Monosyllabic	Passage-Word
Jusczyk et al., 1999a	English	7.5 months	Trochaic Bisyllabic	Word-Passage &
		10.5 months	Iambic Bisyllabic	Passage-Word
Kooijman et al., 2013	Dutch	7 months	Trochaic Bisyllabic	Word-Passage
Kooijman et al., 2009	Dutch	10 months	Iambic Bisyllabic	Word-Passage
Höhle & Weissenborn, 2003	German	8 months	Monosyllabic	Word-Passage

In Experimental Chapter 2, we will present a series of 4 experiments using the segmentation paradigm used in Experimental Chapter 1, to investigate whether French-learning infants have a consonant bias in processing segmented word forms. The aim of this chapter is two-folded: 1) to determine if the C-bias is present in French-learning infants during the first year of life and if so, when it emerges and 2) to determine the origin of the C-bias in French-learning infants.

EXPERIMENTAL CHAPTER 1: EARLY WORD FORM SEGMENTATION

Since words are rarely produced in isolation (Brent & Siskind, 2001) infants have to segment and extract words from speech streams in order to learn the lexicon of their native language. To do so they have access in the speech signal to numerous segmentation cues such as statistical information (transitional probabilities), prosodic, phonotactic and allophonic cues. Nazzi et al. (2006) proposed the early rhythmic segmentation hypothesis which postulates that, very early on, infants will segment speech according to their native language rhythmic unit. According to this hypothesis, infants learning a syllable-based language (e.g., French, Italian, Spanish) will rely on the syllabic unit while infants learning a stress-based language (e.g., English, Dutch, German) will rely on the most common stress pattern present in their native language: the trochaic pattern in English, German and Dutch. There is growing evidence for the early rhythmic segmentation hypothesis in the literature: while English-learning infants are able to segment trochaic units by 7.5 months, they cannot segment the less common iambic pattern before 10.5 months. A similar developmental trajectory is found in Dutch-learning infants (Kooijman et al., 2009, 2013). For several years, evidence of segmentation ability could not be found in French-learning infants before 12 months for syllable segmentation, and 16 months for bisyllabic word segmentation while English-, German- and Dutch-learning infants were found to segment bisyllabic words several months before their first birthday.

However, since Nazzi et al. (2014) recently found evidence of bisyllabic word segmentation in French-learning 8-month-olds (by testing them on the passage-word order not used before in French), we decided to reassess syllabic segmentation in French-learning 8- and 6-month-olds: if the early rhythmic bootstrapping hypothesis (Nazzi et al., 2006) is correct, we should observe syllabic segmentation at the same age or before bisyllabic segmentation (at or before 8 months), similarly to Jusczyk and Aslin (1995) observing that trochaic segmentation (7.5 months) precedes iambic segmentation (10.5 months). In the following, two published papers presenting studies on this issue are reported. The first one (published in Plos One), investigated syllabic segmentation at 8 months by manipulating the distributional properties of the speech stream. The second one (in press in Language and Speech) extended this work to 6-month-olds. Lastly, we will present a replication of the first experiment in Nishibayashi et al. (in press), in preterm 6-month-olds, to explore the impact of preterm birth on segmentation.

1. French-learning 8-month-olds segment syllabic units

Goyet, L., Nishibayashi, L.-L., & Nazzi, T. (2013). Early syllabic segmentation of fluent speech by infants acquiring French. *PloS One*, 8(11), e79646.

*Tables were replaced by appendices and figure numbers were changed from the original paper for coherence within this dissertation.

Abstract

Word form segmentation abilities emerge during the first year of life, and it has been proposed that infants initially rely on two types of cues to extract words from fluent speech: Transitional Probabilities (TPs) and rhythmic units. The main goal of the present study was to use the behavioral method of the Headturn Preference Procedure (HPP) to investigate again rhythmic segmentation of syllabic units by French-learning infants at the onset of segmentation abilities (around 8 months) given repeated failure to find syllabic segmentation at such a young age. The second goal was to explore the interaction between the use of TPs and syllabic units for segmentation by French-learning infants.

The rationale was that decreasing TP cues around target syllables embedded in bisyllabic words would block bisyllabic word segmentation and facilitate the observation of syllabic segmentation. In Experiments 1 and 2, infants were tested in a condition of moderate TP decrease; no evidence of either syllabic or bisyllabic word segmentation was found. In Experiment 3, infants were tested in a condition of more marked TP decrease, and a novelty syllabic segmentation effect was observed. Therefore, the present study first establishes early syllabic segmentation in French-learning infants, bringing support from a syllable-based language to the proposal that rhythmic units are used at the onset of segmentation abilities. Second, it confirms that French-learning infants are sensitive to TP cues. Third, it demonstrates that they are sensitive to the relative weight of TP and rhythmic cues, explaining why effects of syllabic segmentation are not observed in context of high TPs. These findings are discussed in relation to theories of word segmentation bootstrapping, and the larger debate about statistically- versus prosodically-based accounts of early language acquisition.

1.1. Introduction

Infants acquiring language have to learn about the phonology, the lexicon and the syntax of their native language. The present study explores some of the mechanisms involved in learning the lexicon, namely the ability to extract the sound pattern of words from fluent speech (henceforward, word form segmentation). Word form segmentation constitutes a crucial step in lexical acquisition, because most speech directed to infants is constituted of multiword utterances (Aslin, 1993; Brent & Siskind, 2001; van de Weijer, 1998) and its importance for learning words is supported by findings of links between early word segmentation and later vocabulary learning (Graf Estes et al., 2007; Newman et al., 2006). Many studies have explored the emergence of word form segmentation, using either a behavioral method (Headturn Preference Procedure, or HPP) or an electrophysiological method (Evoked-Response Potentials, or ERPs), and have established that this ability emerges between 6 and 12 months of age in infants learning English (Jusczyk & Aslin, 1995; Saffran et al., 1996b), Parisian French (Goyet et al., 2010; Nazzi et al., 2006; Nazzi et al., 2014), Canadian French (Polka & Sundara, 2012; Shi, Marquis, & Gauthier, 2006), Dutch (Houston et al., 2000) and German (Höhle & Weissenborn, 2003). The goal of the present study is to determine the procedures that infants use to segment speech when this ability emerges, focusing on French-learning infants in order to establish early rhythmic-based segmentation and to directly explore the relative importance of rhythmic and distributional information. Previous research has established that during the first year of life, infants use many subtle linguistic cues present in the signal to segment fluent speech. These cues include transitional probabilities (TPs) between syllables (Johnson & Jusczyk, 2001; Mersad & Nazzi, 2012; Saffran et al., 1996b; Thiessen & Saffran, 2003), the rhythmic unit of the native language (Curtin et al., 2005; Jusczyk et al., 1999a; Nazzi et al., 2006; Nazzi et al., 2014), prosodic boundaries (Gout et al., 2004; Seidl & Johnson, 2006), co-articulatory cues (Johnson & Jusczyk, 2001), allophonic information (Jusczyk et al., 1999b; Mattys & Jusczyk, 2001b), phonotactic information (Gonzalez-Gomez & Nazzi, 2013; Mattys & Jusczyk, 2001a; Mattys et al., 1999) and pitch accent (Nazzi, Dilley, Jusczyk, Shattuck-Hufnagel, & Jusczyk, 2005). The first two cues (TPs and rhythmic units), which are further explored in the present study, have received the most attention and have been proposed as crucial at the onset of word segmentation (Saffran et al., 1996b; Nazzi et al., 2006; Jusczyk et al., 1999a). This interest

initially stems from the fact that they are both seen as instantiations, at the level of early word form segmentation, of the debate between two dominant visions of language acquisition. On the one hand, the use of TPs is linked to the proposal that infants are able to perform sophisticated statistical analyses of the speech signal that will allow them to discover many properties of their native language, such as its phoneme inventory (Maye, Werker, & Gerken, 2002), its lexicon (Saffran, Johnson, Aslin, & Newport, 1999), or aspects of its syntactic properties (Gomez & Gerken, 1999; Saffran, Hauser, Seibel, Kapfhamer, Tsao et al., 2008). On the other hand, the use of rhythmic unit cues is linked to “prosodic or phonological bootstrapping” theories (Morgan & Demuth, 1996) claiming that the speech signal contains many acoustic/prosodic cues that also allow infants to learn properties of their native language, such as its basic rhythm (Nazzi, Bertoncini, & Mehler, 1998), its lexicon and some properties of that lexicon (Jusczyk et al., 1993a, 1999a; Gleitman & Wanner, 1982), or its syntactic structure (Höhle et al., 2009; Hirsh-Pasek et al., 1987). While these two theoretical perspectives were initially considered to be in opposition (Johnson & Jusczyk, 2001; Mersad & Nazzi, 2012; Saffran et al., 1999; Thiessen & Saffran, 2003), a more recent position is that they might both contribute to language acquisition, and current work is trying to understand how the two types of cues are used in combination (e.g., Bernard & Gervain, 2012; Hay & Saffran, 2012; Mersad & Nazzi, 2012). The present project contributes to this debate.

Hence, in the context of early segmentation, it has been proposed that the combined use of (statistical) TPs that are taken to be language-general and rhythmic units that differ across classes of languages could account for early differences in segmentation abilities across languages, in particular between English-learning infants relying on trochaic units and French-learning infants relying on syllabic units. However, the evidence for the early use of syllabic units is limited as research on Parisian French has repeatedly failed to find evidence in its favor before 12 months (Nazzi et al., 2006, 2014) while syllabic effects found in Canadian French 8-month-olds (Polka & Sundara, 2012) might come from post-lexical processes rather than segmentation processes. This limited evidence thus weakens the rhythmic unit proposal in general (see more below). The present study re-explores this issue, and examines how combined use of rhythmic units and TP information might explain previous failures to show early syllabic segmentation in Parisian infants. Before presenting the study itself, we review in more detail the literature on segmentation based on TPs and rhythmic units.

Regarding distributional information, most studies used the HPP to explore infants' ability to use transitional probabilities between adjacent syllables (TPs), which refer to regularities in the order of syllables in the speech signal (for a pair of events 'xy', forward TPs measure the strength with which 'x' predicts 'y' while backward TPs measure the strength with which 'y' predicts 'x'), and appeared important given that TPs are higher within than across words (Curtin et al., 2005). By using an artificial language paradigm in which infants are presented with a continuous sequence made-up of randomly ordered repetitions of 4 trisyllabic pseudo-words, English-learning 6- and 8-month-olds were found to group syllables into cohesive word-like units on the basis of syllabic distributional information (Aslin, Saffran, & Newport, 1998; Saffran et al., 1996b; Thiessen & Saffran, 2003), a finding later extended to natural language situations (Pelucchi et al., 2009).

Similar results were found at the same age in Dutch-learning (Johnson & Tyler, 2010) and French-learning (Mersad & Nazzi, 2012) infants. Interestingly, the use of distributional cues appears to be wide ranging, and was found in non-human primates (Hauser, Newport, & Aslin, 2001) and for the perception of musical sequences by human infants (Saffran et al., 1999). However, some limits in infants' ability to use TPs for segmentation have been found when using more complex languages (Johnson & Jusczyk, 2001; Johnson & Tyler, 2010; Mersad & Nazzi, 2012). Therefore, current research is exploring how TPs are used in conjunction with other cues in more complex experimental situations (Mersad & Nazzi, 2012; Pelucchi et al., 2009; Thiessen & Saffran, 2003) an issue that will also be addressed here.

The use of the rhythmic (prosodic) unit of the native language has been formalized in the early rhythmic segmentation hypothesis (Nazzi et al., 2006). This hypothesis states that infants use the rhythmic unit on which the rhythm of their native language is based to segment the continuous speech stream. Given that languages have different rhythmic units (the syllable in syllable-based languages such as French and Italian; the trochaic or strong-weak stress unit in stress-based languages such as English, Dutch and German (Abercrombie, 1967; Pike, 1945), this hypothesis predicts that there should be cross-linguistic differences in the way segmentation mechanisms will be established during development.

Evidence for the rhythmic-based hypothesis initially comes from studies on stress-based languages. These HPP studies suggest that after having developed a bias for

trochaic stress units (Jusczyk et al., 1993a for English; Höhle et al., 2009 for German), English-learning infants use this rhythmic information by 8 months of age to segment fluent speech into trochaic units (Curtin et al., 2005; Echols et al., 1997; Houston et al., 2004; Johnson & Jusczyk, 2001; Jusczyk et al., 1999a; Morgan & Saffran, 1995; Nazzi et al., 2005). For example, after having been familiarized with repetitions of trochaic target bisyllabic words (uttered in isolation), 7.5-month-old infants show a preference for passages containing the target bisyllabic words presented in a test phase. However, they do not show a preference for the same passages after having been familiarized with only the stressed syllables of the trochaic words, suggesting they do not extract and then recognize the individual stressed initial syllables from the trochaic words (Jusczyk et al., 1999a). These findings using the word-passage order (familiarization with isolated targets and test with passages containing or not containing the targets) were replicated in the passage-word order (in which the order of presentation of the stimuli between familiarization and test is reversed, hence a familiarization with passages and test with isolated targets and controls) (Jusczyk et al., 1999a). Convergent findings have also been obtained in young Dutch-learning infants using HPP (Houston et al., 2000; Kooijman, 2007) and ERPs (Kooijman, 2007; Kooijman et al., 2005, 2009). Therefore, results on English- and Dutch-learning infants are compatible with the notion that the trochaic unit is used at the onset of word form segmentation by infants learning stress-based languages.

For syllabic-based segmentation in syllable-based languages, all existing research focuses on French-learning infants. However, the studies have not provided any clear evidence of syllabic segmentation at the onset of this ability around 8 months of age. Most studies on this topic have tested Parisian infants learning European French. While Gout (2001) found that 7.5-month-old Parisian infants can segment monosyllabic words in the word-passage order, it should be noted that this does not establish the role of the syllabic unit given that the lexical and syllabic levels are confounded in monosyllabic words. In order to establish syllabic segmentation, one needs to show that infants can segment syllables embedded in multisyllabic words. Accordingly Nazzi et al. (2006), investigated if infants can segment bisyllabic words or each of their individual syllables from passages, after having been familiarized with lists of either the bisyllabic target words or one of their syllables (word-passage order). Their results failed to find any evidence of segmentation at 8 months, but established syllabic segmentation at 12 months (with stronger evidence for the segmentation of the word-final syllables), and bisyllabic

segmentation at 16 months. This pattern of results suggests a precedence in developmental time of syllabic over whole (multisyllabic) word segmentation in French, in accordance with the syllable-based segmentation hypothesis. However, this precedence of syllabic segmentation was challenged by follow-up studies using different methods (HPP or ERPs) and variants of the procedure (use of the word-passage or passage-word orders). Indeed, results using ERPs suggested that Parisian 12-month-olds could access both the syllabic and the whole word levels (Goyet et al., 2010). Moreover, when tested in the word-passage order, Canadian French 8-month-olds were found to recognize not only the target bisyllabic words (familiarity preference), but also their initial syllables (novelty preference) and marginally their final syllables (novelty preference) (Polka & Sundara, 2012). Even more problematic for the syllable-based segmentation hypothesis, a study using the stimuli by Polka and Sundara (2012) and the passage-word order (familiarization with passages, test with either the target bisyllabic words or their final syllables) found evidence of bisyllabic word segmentation (while replicating the lack of evidence of bisyllabic word segmentation in the word-passage order), but no such evidence for their final syllables in Parisian 8-month-olds (Nazzi et al., 2014). These last findings suggest that both Parisian and Canadian French-learning infants can segment bisyllabic words at 8 months. While there is no evidence that Parisian 8-month-olds segment syllables, the results by Polka and Sundara (2012) suggest that Canadian 8-month-olds might also segment individual syllables. However, the fact that they found a novelty rather than a familiarity effect when looking at syllabic segmentation calls for a replication. Moreover, it is unclear from their study whether the recognition of the target syllable preceded the recognition of the bisyllabic word it was embedded in, or whether it was the segmentation and recognition of the bisyllabic word that allowed the later recognition of the syllable. In the latter case, the observed syllabic effect would not be an effect of segmentation, but rather a product of “post-lexical” processing. The above findings thus seem contrary to the prediction of syllable-based segmentation, and therefore appear to invalidate the early rhythmic segmentation hypothesis. If so, a more parsimonious interpretation of the findings so far might be that TPs are the primary cues to early word segmentation in all languages and that prosody is only a secondary cue that would play a role only in language-specific ways – in the present case, only in languages in which there is a clear trochaic bias in the lexicon. However Nazzi et al. (2014), proposed a way in which their findings could be reconciled with syllable-based segmentation, and

hence, with the early rhythmic segmentation hypothesis, which is tested in the present study. The idea is that 8-month-old Parisian infants use both the rhythmic unit of their native language (the syllable) and TPs to segment words. Evidence of bisyllabic word segmentation in their study was only found in the passage-word order because in that order, infants have time during familiarization to segment syllabic units and conduct some analyses to retrieve distributional information (whether forward or backward TPs, all equal to 1 in the stimuli used) that will allow them to group together the two syllables of the bisyllabic words. As a corollary, the use of the syllabic unit was masked because the syllables infants had to detect were always part of bisyllabic words, so that high TPs induced grouping of the two syllables of the target words. Therefore, the goal of the present study was to reevaluate syllabic segmentation in light of this hypothesis by testing Parisian 8-month-old infants in the passage-word order and, crucially, using passages in which the strength of the distributional (TP) cues was gradually manipulated. In all previous studies exploring syllabic segmentation (Nazzi et al., 2006, 2014; Polka & Sundara, 2012), forward and backward TPs between the two syllables of the bisyllabic words were equal to 1, because the two syllables of the target words always appeared together. In the present study, TP information was reduced by selecting, for each target syllable, several words sharing that syllable. Two levels of decreased distributional information were used, a moderate one in which each target syllable was shared by two bisyllabic words (e.g., *diva/radis*; Experiments 1 and 2), and an even more marked decrease in which each target syllable was shared by 8 different words (Experiment 3). While Nazzi et al. (2014) found a pattern of results in which bisyllabic words, but not their individual syllables, were found to be segmented, we predicted that the present manipulations should reverse this pattern, and allow us to observe segmentation of syllables, but not bisyllabic words. Syllabic segmentation was tested for both manipulation levels (Experiments 1: moderate decrease and 3: marked decrease), and bisyllabic word segmentation only for the moderate level (Experiment 2).

1.2. Experiment 1: syllabic segmentation at 8 months (moderate TP decrease)

The aim of Experiment 1 was to reevaluate syllabic segmentation in (Parisian) French-learning 8-month-olds in a context of moderate reduction of distributional information around the target syllables. Accordingly, infants were familiarized with two passages (each made up of 8 sentences), each corresponding to a different target syllable (e.g., /di/ and /pu/), and each containing two bisyllabic words sharing that target syllable in either word-initial or word-final position (e.g., /diva/-/radi/ for the /di/ syllable). Then, they were tested with two lists of the repeated target syllables and two lists of repeated control syllables. In this context, the forward TPs for the words with the target syllables in word-initial versus word-final positions were .5 and 1 respectively, while the backward TPs for the same words were 1 and .5. We predicted that if such a moderate reduction of TP information within the bisyllabic words compared to Nazzi et al. (2014) is enough to give less weight to TP relative to rhythmic-based segmentation, then French-learning 8-month-old infants might show a syllable-based segmentation effect in the present experiment, and no bisyllabic word segmentation effect in Experiment 2.

1.2.1. Method

Ethics statement

Parents of all infant participants provided written informed consent prior to the experiment. The experimental protocol and consent procedure were both approved by the CERES (Comité d'évaluation éthique des projets de recherche) of the Université Paris Descartes. All data were obtained according to the principles expressed in the Declaration of Helsinki.

Participants

Twenty 8-month-old infants (mean age: 8.3 months; range: 7.8-8.8 months) from French-speaking families were tested (9 females and 11 males). Data from four additional infants were excluded from the analysis due to fussiness (3) or due to a segmentation index (defined as the difference between the mean orientation times to the lists of target and control syllables) more than 2 SDs above or below the group mean (1). All infants were full term, had no major problem during pregnancy and birth and had normal development and hearing. Their parents had neither hearing impairment nor language

problems. The infants were recruited through birth lists from the Paris area and parents gave a written informed consent.

Stimuli

As done in previous research on this topic, we selected stimuli with relatively low frequencies, using the adult database LEXIQUE (New, et al. 2004) (given per 1 million occurrences, and calculated over a base of 31 million occurrences). We selected four syllables with relatively low frequencies in the initial and final positions of French words: /ba/ (initial position: 5.99; final position: 14.12); /di/ (initial position: 16.10; final position: 5.94); /pu/ (initial position: 5.19; final position: .09) and /tɔ̃/ (initial position: 62.84; final position: 7.48). For each syllable, two target words that start or end with that syllable were also chosen for their relatively low frequencies: syllable /ba/: *bassin-tuba* (/basɛ̃/-/tyba/, [pool-tuba]; word frequency: .07 and .54, respectively); syllable /di/: *diva-radis* (/diva/-/radi/, [diva]-[raddish]; word frequency: 1.28 and 3.11, respectively) syllable /pu/: *poulain-quipou* (/pulɛ̃/-/kipu/, [young horse]-[quipou]; word frequency: 3.04 and .07, respectively); syllable /tɔ̃/: *tombeau-jeton* (/tɔ̃bo/-/ʒɛtɔ̃/, [grave]-[chip]; word frequency: 11.96 and 10.27, respectively). There was no semantic link between the target words sharing the same syllable. All these items are likely to be unknown to the infants tested given their relatively low frequencies in the adult lexicon LEXIQUE, and the fact that they do not appear in the infant (8-16 months) version of the French MCDI (Kern, 2003), a checklist of French words acquired at an early age, except for “ton”, which however is known by 0% of infants at 8 months.

Lastly, for each syllable, four passages (sentences) were created, each made up of eight sentences. In each passage, half of the sentences contained a bisyllabic target word, and the other half contained the other bisyllabic target word sharing the same target syllable. The target syllables in word-initial positions were always preceded by different syllables; similarly, the target syllables in word-final positions were always followed by different syllables (see Appendix 1.1.). There was no semantic link between the sentences in each passage (as done in previous studies, e.g., Jusczyk & Aslin, 1995 for English; Nazzi et al., 2006, for French).

Recordings were made in a sound-attenuated booth. A female native speaker of French first recorded the four passages. She was asked to produce the stimuli as if speaking to an infant. All the passages were 20 s long and the sentences were separated by a mean ISI of 560 ms. The target syllables in the passages had an average duration of

155 ms in initial position and 154 ms in final position. Their mean intensity was 72 and 70 dB respectively, and their mean pitch was 230 and 236 Hz respectively.

For each target syllable, the same talker also produced a list of 20 isolated occurrences for use in the test phase. The talker produced the tokens with some variation, as in previous research (Juszyk & Aslin, 1995 for English; Nazzi et al., 2006, for French), in order to prevent infants' boredom when listening to the test lists, and also to evaluate recognition of the targets at test in a condition with some acoustic variability. The duration of each list was 20 s and the syllables were separated by a mean ISI of 740 ms. The target syllables in the lists had an average duration of 275 ms, a mean intensity of 76 dB and a mean pitch of 224 Hz.

Procedure, apparatus and design

The experiment was conducted in a sound-attenuated booth, which contained a three-sided test booth made of pegboard panels. The test booth had a red light and loudspeakers (Sony xs-F1722) mounted on each of the side panels and a green light mounted on the central panel. Directly below the center light, a 5-cm hole accommodated the lens of a video camera used to monitor infants' behavior. A PC computer terminal (Dell Optilex computer), audio amplifier (Marantz PM4000), TV screen and response box were located outside the sound-attenuated room. The stimuli were stored in digitized form on the computer and were delivered by the loudspeakers via the amplifier. The response box, which was connected to the computer, was equipped with 3 buttons. The box was controlled by an observer, outside the sound-attenuated booth, who watched the video of the infant on the TV screen and pressed the buttons according to the direction the infant's headturns, thus starting and stopping the flashing of the lights and the presentation of the sounds. The observer and the infant's caregiver wore earplugs and listened to masking music over tight-fitting headphones, which prevented them from hearing the stimuli. Information about the direction and duration of the headturns/orientation times were stored in a data file on the computer.

The variant of HPP set up by (Juszyk & Aslin, 1995) was used in the present experiment. Each infant was held on a caregiver's lap and the caregiver was seated in a chair at the center of the test booth. Each trial began with the green light on the center panel blinking until the infant had oriented in that direction. Then the center light was extinguished and the red light above the loudspeaker on one of the side panels began to flash. When the infant made a turn of at least 30° in the direction of the loudspeaker, the

stimulus for that trial was played, the red light continuing to flash for the entire duration of the trial. Each stimulus was played to completion (i.e., when the eight sentences of a given passage had been presented) or stopped immediately after the infant failed to maintain the 30° headturn for two seconds. If the infant turned away from the red light for less than two seconds and then turned back again, the trial continued but the time spent looking away was not included in the orientation time. Thus, the maximum orientation time for a given trial was the duration of the entire speech sample. If for a trial, the infant's orientation time was shorter than 1.5 seconds, the trial was immediately replayed and the initial orientation time was discarded.

Each experimental session began with a familiarization phase in which infants heard two passages on alternating trials until they accumulated 30 s of orientation times to each. When the infants reached the familiarization criterion for one passage, the second passage continued to be presented until its criterion was also reached. The side of the loudspeaker from which the stimuli were presented was randomly varied from trial to trial. The test phase began immediately after the familiarization criterion was reached. It consisted of three test blocks, in each of which the four lists of isolated syllables were presented. The order of the lists within each block was randomized.

Half of the infants were familiarized with the /ba/ and /tʃ/ passages (Condition 1), and the other half with the /di/ and /pu/ passages (Condition 2). All the infants were tested with the four lists of syllables. Therefore, the target syllables were /ba/ and /tʃ/ for the infants in Condition 1, and /di/ and /pu/ for the infants in Condition 2.

1.2.2. Results and Discussion

The analyses were conducted following the same data analyses as done in previous studies using this kind of segmentation paradigm (e.g., Jusczyk & Aslin, 1995 for English Nazzi et al., 2006, 2014, for French). Mean orientation times to the lists containing the target versus the control syllables were calculated for each infant (see Figure 1.1, left panel). In this kind of study, differences in orientation times to the target versus the control test stimuli are taken as evidence that infants have segmented the targets from the passages and recognized them in the test phase. Therefore, a 2-way ANOVA with the main between-subject factor of Condition (Conditions 1-2) and the main within-subject factor of Familiarity (lists of target syllables heard during familiarization versus lists of control syllables not heard during familiarization) was conducted. The effect of

Familiarity did not reach significance ($F(1,18) = .02$, $p = .86$, $\eta^2 = .001$), indicating that infants had similar orientation times to the target ($M = 6.15$ s, $SD = 1.64$) and control ($M = 6.20$ s, $SD = 1.33$) syllables. Moreover, only 9 of the 20 infants oriented longer to the familiar lists (binomial test, $p = .74$). Neither the effect of Condition ($F(1,18) = 1.76$, $p = .19$) nor the Familiarity x Condition interaction ($F(1,18) = 1.77$, $p = .19$) reached significance.

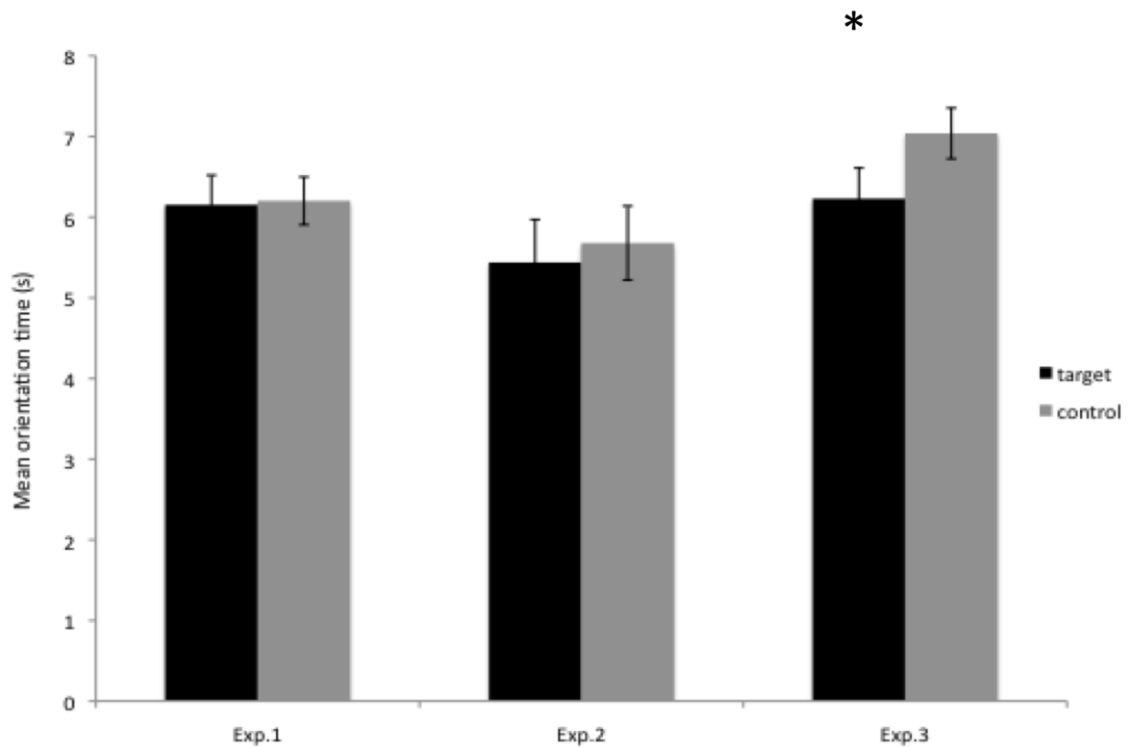


Figure 1.1. Mean orientation times (and SEs) to the target vs. control syllables in Experiments 1 – 3. Retrieved from Goyet, Nishibayashi, & Nazzi (2013).

Experiment 1 fails to reveal a syllabic segmentation effect at 8 months of age and is thus in line with previous studies that failed to find syllabic effects in young Parisian French-learning infants (Nazzi et al., 2006, 2014). This failure is found in spite of the fact that we have moderately decreased the relative weight of TP information by associating each target syllable with two bisyllabic words (e.g., for the syllable /di/: /diva/-/radi/). One possible reason for the failure to segment syllables is that TPs were still too high (moderate decrease) between the syllables of the target bisyllabic words, and that infants, as in Nazzi et al. (2014) were segmenting the bisyllabic target words rather than their individual syllables. This possibility was explored in Experiment 2, in which infants were

familiarized with the same passages as in Experiment 1, but then tested on their recognition of the whole bisyllabic words and not on their isolated syllables.

1.3. Experiment 2: bisyllabic word segmentation at 8 months (moderate TP decrease)

The aim of Experiment 2 was to evaluate whether French-learning 8-month-olds segment bisyllabic words rather than individual syllables from the passages used in Experiment 1, thus in a context of moderate decrease of TP information. Accordingly, they were familiarized with two passages, each corresponding to a different target syllable (e.g., /di/ and /pu/), and each containing two bisyllabic words sharing that target syllable in either word-initial or word-final position (e.g., /diva/-/radi/ for the /di/ syllable), and then tested with two lists of the target bisyllabic words and two lists of control words.

1.3.1. Method

Participants

Twenty 8-month-old infants (mean age: 8.2 months; range: 7.7-8.7 months) from French-speaking families were tested (13 females and 7 males). Data from four additional infants were excluded from the analysis due to fussiness (4). Infants were recruited following the same procedure and criteria as in Experiment 1.

Stimuli

The familiarization stimuli were the same passages as in Experiment 1. The pair of target words in the passages had an average duration of 340 ms. Their mean intensity was 71 dB, and their mean pitch was 232 Hz. The female talker of Experiment 1 had also recorded four lists of 20 alternating target words, again as if speaking to an infant, and with some variation, one for each target syllable, which were used in the present test phase. The duration of each list was 20 s and the words were separated by a mean ISI of 560 ms. The target words in the lists had an average duration of 482 ms, a mean intensity of 70 dB and a mean pitch of 200 Hz.

Procedure, apparatus and design

The procedure and apparatus were identical to Experiment 1. Half of the infants were familiarized with the /ba/ and /tʃ/ passages (Condition 1), and the other half with the /di/ and /pu/ passages (Condition 2). All the infants were tested with the four lists of pair of bisyllabic words.

1.3.2. Results and Discussion

As for the test phase of Experiment 1, mean orientation times to the lists containing the target versus the control words were calculated for each infant (see Figure 1.1., middle panel). A 2-way ANOVA with the between-subject factor of Condition (Conditions 1-2) and the within-subject factor of Familiarity (lists of target words heard during familiarization versus lists of control words not heard during familiarization) was conducted. The effect of Familiarity did not reach significance ($F(1,18) = .022$, $p = .64$, $\eta^2 = .011$), indicating that infants had similar orientation times to the target ($M = 5.44$ s, $SD = 2.13$) and control ($M = 5.68$ s, $SD = 1.84$) words. Moreover, only 10 of the 20 infants oriented longer to the familiar lists (binomial test, $p = .58$). Neither the effect of Condition ($F(1,18) = 0.75$, $p = .39$) nor the Familiarity x Condition interaction ($F(1,18) = .62$, $p = .43$) reached significance.

Experiment 2 failed to provide evidence that infants were segmenting whole bisyllabic words from the passages. These results differ from Nazzi et al. (2014), who showed using the same procedure that French-learning 8-month-olds are able to segment bisyllabic words. One possible reason for the present lack of a segmentation effect could be the alternation between the two target words in both the familiarization and the test phases, which could have made the task more difficult for the infants. More interestingly, the lack of bisyllabic word segmentation in Experiment 2, paired with the lack of syllabic segmentation in Experiment 1, is likely to be due to our TP manipulation. It is possible that having moderately decreased the TPs around the target syllables by embedding them in two rather than one word was enough to block the segmentation of the bisyllables without allowing us to observe syllabic segmentation. Since finding evidence of syllabic segmentation at 8 months in Parisian French-learning infants is the main focus of the present study, Experiment 3 was conducted to evaluate this issue in a context of even more decreased TP cues.

1.4. Experiment 3: syllabic segmentation at 8 months (marked TP decrease)

The aim of Experiment 3 was again to assess syllabic segmentation in French-learning 8-month-olds, in a context of even lower TPs (marked decrease) than in the passages used in Experiments 1 and 2. Accordingly, French-learning 8-month-olds were familiarized with new passages, each containing 8 different target words that all shared a target syllable. For example, for the passage corresponding to the target syllable /di/, half of the words contained the target syllable in word-initial position (*divan, dizain, dîner, dito*) while the other half contained the same target syllable in word-final position (*bandit, taudis, caddie, radis*; all target syllables being pronounced as /di/ no matter the spelling, see stimuli section below). Thus in Experiment 3, the forward TPs for the words with the target syllables in word-initial versus word-final positions were .125 and 1 respectively, while the backward TPs for the same words were 1 and .125. We predicted that if this much more drastic reduction of TP information within the bisyllabic words compared to Experiment 1 is enough to cause infants to give less weight to TP- relative to rhythmic-based segmentation, then French-learning 8-month-old infants might show a syllable-based segmentation effect in this third experiment.

1.4.1. Method

Participants

Twenty 8-month-old infants (mean age: 8.3 months; range: 7.9-9.2 months) from French-speaking families were tested (7 females and 13 males). Data from one additional infant were excluded from the analysis due to fussiness. Infants were recruited following the same procedure and criteria as in Experiments 1 and 2.

Stimuli

In this experiment, three of the four syllables chosen as stimuli differed from the ones used in Experiment 1 because eight relatively low frequency words per syllable needed to be selected, and this was only possible for one of the syllables used in Experiment 1. Therefore, we again used Lexique (New, Pallier, Brysbaert, & Ferrand, 2004) to select four syllables with relatively low frequencies (again given per 1 million of occurrences) in initial and final positions of French words: /di/ (initial position: 11.39; final position: 4.56), /gu/ (initial position: 2.01; final position: 6.52), /po/ (initial position: 6.87; final position: 6.15) and /te/ (initial position: 3.7; final position: 11.95). For each

syllable, eight words were chosen for their low frequencies. For example, for the syllable /di/, we used: *divan* (/divã/, [couch], 21.55), *dizain* (/dizĩ/, [dizain], .00), *diner* (/dine/, [dinner], 60.0), *ditto* (/dito/, [ditto], .34), *bandit* (/bãdi/, [outlaw], 4.59), *taudis* (/todi/, [hovel], 3.24), *caddie* (/cadi/, [caddy], 1.28), *radis* (/radi/, [radish], 3.11). There was no semantic link between the 8 words sharing a given syllable. All these items are likely to be unknown to the infants tested given their relatively low frequencies in the adult lexicon LEXIQUE, and the fact that they do not appear in the infant (8-16 months) version of the French MCDI (Kern, 2003), except for “pot”, which however is known by only 3% of infants at 8 months.

Lastly, four passages were created for each target syllable (passages /di/, /gu/, /po/, /te/). Each passage was made up of 8 sentences (one for each of the 8 bisyllabic words) in which the target syllable was in initial position of four words and in final position of the other four words. The target syllables in word-initial positions were always preceded by different syllables; similarly, the target syllables in word-final positions were always followed by different syllables (see Appendix 1.2.). There was no semantic link between the different sentences in each passage (as done in previous studies, e.g., Jusczyk & Aslin, 1995 for English; Nazzi et al., 2006, for French).

As in Experiments 1 and 2, recordings were made in a sound-attenuated booth. The same female talker recorded the four passages. The talker was again asked to produce the stimuli as if speaking to an infant. All the passages were 20 s long and the sentences were separated by an ISI of 480 ms. The target syllables in the passages had an average duration of 133 ms in initial position and 147 ms in final position. Their mean intensity was 74 and 70 dB respectively, and their mean pitch was 216 and 227 Hz respectively.

For each target syllable, the same talker also produced a list of 20 isolated occurrences for use in the test phase. Again, the talker produced the tokens with some variation. The duration of each list was 20 s and separated by a mean ISI of 590 ms. The target syllables in the lists had an average duration of 255 ms, a mean intensity of 74 dB, and a mean pitch of 217 Hz.

Procedure, apparatus and design

The procedure and apparatus were identical to Experiment 1. Half of the infants were familiarized with the passages /di/ and /po/ (Condition 1) and the other half with the passages /gu/ and /te/ (Condition 2). All the infants were tested with the same four

lists of syllables. Therefore, the target syllables were /di/ and /po/ for the infants in Condition 1, and /gu/ and /te/ for the infants in Condition 2.

1.4.2. Results and Discussion

Again, mean orientation times to the lists containing the target versus the control syllables were calculated for each infant (see Figure 1.1., right panel). A 2-way ANOVA with the between-subject factor of Condition (Conditions 1-2) and the within-subject factor of Familiarity (lists of target syllables heard during the familiarization phase versus lists of control syllables not heard during the familiarization) was conducted. The effect of Familiarity was significant ($F(1,18) = 5.09$, $p = .03$, 64 , $\eta^2 = .220$, large effect), indicating that infants had a preference for the control ($M = 7.04$ s, $SD = 1.4$) over the target ($M = 6.22$ s, $SD = 1.71$) syllables. Moreover, 15 out of 20 infants oriented longer to the control than to the target lists (binomial test, $p = .02$). Neither the effect of Condition ($F(1,18) = 1.12$, $p = .30$), nor the Familiarity x Condition interaction ($F(1,18) = .07$, $p = .78$) reached significance.

The present results show that Parisian French-learning 8-month-olds, familiarized with passages containing target syllables, react differently to presentation of repetitions of these syllables versus control syllables during the test phase. The present findings are thus the first to directly establish sensitivity to the syllabic unit at the brink of word form segmentation, as predicted for syllable-based languages such as French by the early rhythmic-based segmentation hypothesis. This result thus demonstrates syllabic segmentation effects earlier than had previously been found (Goyet et al., 2010; Nazzi et al., 2006 for 12-month-olds).

Before further discussing in the General Discussion why such a clear syllabic segmentation effect had not been observed in past studies at 8 months of age, we would like to address one feature of our finding, namely that the segmentation effect corresponded to a novelty effect (infants preferred to orient to the control syllables over the familiar syllables) rarely found in segmentation studies. Interestingly, this novelty effect was also found in Polka and Sundara (2012) when they tested whether Canadian French infants familiarized with the initial or final syllables of bisyllabic words would later listen differently to passages containing these bisyllables and to control passages (while they found a familiarity effect for bisyllabic word segmentation). However, familiarity effects for monosyllabic word segmentation in Parisian 8-month-olds were

found in both the word-passage (Gout, 2001) and passage-word orders (unpublished data from our group). Taken together, these findings raise the possibility that these novelty effects are due to the fact that infants are reacting differently according to whether the target syllables correspond to a word or are part of a word. This suggests that French-learning infants might be sensitive to word boundary cues or coarticulation factors that are stronger within words than across word boundaries, as found for young English-learning infants (Johnson & Jusczyk, 2001; Shukla, White, & Aslin, 2011).

1.5. General Discussion

The main goal of the present study was to provide evidence for early syllabic segmentation in French-learning infants, as predicted by the early rhythmic segmentation hypothesis for syllable-based languages like French. More precisely, we re-evaluated French-learning 8-month-olds' ability to segment syllabic units, given that such effects have never been found before 12 months in Parisian infants (Goyet et al., 2010; Nazzi et al., 2006, 2014); see below for a discussion of the results by Polka and Sundara (2012) with Canadian French infants), in two experimental contexts varying in the distributional properties of the passages to be segmented. While the results of Experiments 1 and 2 revealed neither syllabic nor whole word segmentation (in a context of moderate TP decrease), a syllabic segmentation was found in Experiment 3 in which the decrease in TPs was more pronounced.

Interestingly, in spite of methodological differences (different stimuli, different test orders, etc.), our results converge with those of Polka and Sundara (2012) that found in the word-passage order that Canadian French-learning 8-month-olds familiarized with passages containing bisyllabic words recognize both the bisyllables (familiarity effect) and their individual syllables (novelty effects, marginal for final syllables, significant for initial syllables). These previous findings suggested that Canadian French-learning 8-month-olds were also accessing the syllabic level, together with the lexical level. However, as we argued above, it was unclear from their study whether the recognition of the target syllables preceded the recognition of the bisyllabic words they were embedded in, or whether it was the segmentation and recognition of the bisyllabic words that allowed the later recognition of the syllables (thus, a post-lexical effect in this latter case). This ambiguity does not arise with our study. Indeed, if the present syllabic effects were the

reflection of post-lexical processing, this would mean that infants in Experiment 3 would have had access to each target syllable after having segmented (some of) the eight bisyllabic words per passage in which it was embedded. This is likely a very difficult task at this age. Moreover, if it were the case, it would be intriguing that they would not have done the same in Experiment 1, given that there were only two target words per passage; however, Experiment 2 provides no evidence that 8-month-olds were indeed segmenting the bisyllabic words in the passages used in both Experiments 1 and 2. Therefore, a more parsimonious interpretation of the finding of Experiment 3 is that it shows that Parisian French-learning infants can segment syllabic units from fluent speech at 8 months, but that this can only be observed under specific experimental conditions.

Our study, together with Polka and Sundara (2012), allows us to specify the conditions under which syllabic segmentation is observed (passage-word order: present Experiment 3) or not (word-passage order Nazzi et al., 2006; passage-word order Nazzi et al., 2014; present Experiment 1) at 8 months. First, the main difference between Experiment 3 and Nazzi et al. (2006) is a change in stimuli presentation order, so that in the test phase, when their behavior was measured, infants were hearing lists of isolated syllables rather than passages. Together with the finding that infants can segment bisyllabic words in the passage-word but not the word-passage order (Nazzi et al., 2006, 2014), it appears that it is easier for Parisian French-learning infants to show evidence of segmentation in the passage-word order. It was suggested that this might in part be due to them having more time to process the passages in the passage-word than word-passage order Nazzi et al. (2014).

Second, and more importantly, the results of the present Experiment 3 differ from those of Nazzi et al. (2014) and our Experiment 1, both of which tested infants in the same passage-word order. The crucial difference between these three experiments relates to the strength of TPs within the passages, which was maximal in Nazzi et al. (2014), moderate in Experiment 1, and lowest in Experiment 3. Taken together, these experiments thus establish not only that French-learning 8-month-olds use syllables to segment speech, but also that they use TP information (confirming data from Mersad & Nazzi, 2012, obtained in an artificial language paradigm), and that infants are sensitive to the relative strength of the two cues. This is attested by the fact that a syllabic effect is only observed when TP cues are the weakest (Exp. 3), but not when they are moderate (Exp. 1) or high (as in Nazzi et al., 2014). When syllabic segmentation is not observed, we

suggest that it does occur in a first segmentation step, but because infants also process TP information regarding the fact that certain syllables are likely to be part of a bisyllabic unit, the recognition of the syllable is blurred by the formation of the bisyllabic unit. Note that the formation of the bisyllabic unit is also influenced by the strength of the TP cue: while high TPs led to formation and recognition of the bisyllabic targets in Nazzi et al. (2014), the moderate decrease in TP cues of the stimuli used for the present Experiments 1 and 2 probably did not allow the formation of stable enough bisyllabic units, leading to a lack of recognition of these units in Experiment 2.

Therefore, the present findings are the first ones to demonstrate that French-learning infants use the rhythmic unit of their native language (the syllable) to segment fluent speech at the time in development when this ability emerges (while confirming it is not observed under every condition). They complement previous findings on two stress-based languages, English and Dutch, which had established that these infants use the rhythmic unit of their native language, the trochaic stress unit, when segmentation emerges (Jusczyk et al., 1999a; Kooijman et al., 2005, 2009). Our results thus bring crucial support, from a language of a different rhythmic class, to the early rhythmic-based segmentation hypothesis that has been proposed to be essential for the emergence of segmentation procedures (Nazzi et al., 2006). This piece of evidence is crucial since it validates this general proposal, rather than the more restricted interpretation of the English and Dutch data presented earlier (according to which the rhythmic cue is a secondary cue, used only in some languages with trochaically-biased lexicons, while TPs would be the primary, default, language-general segmentation cue). Our findings thus establish the early use in segmentation of two different rhythmic units (the syllabic unit, the trochaic units), used by infants appropriately according to the rhythmic properties of their native language. What future work will have to specify is how the specific rhythmic unit of the native language is acquired before the onset of segmentation abilities. One proposal is that this acquisition might rely on newborns' sensitivity to the global rhythm of languages and on infants' rapid acquisition of the native rhythm of their native language by 5 months of age (Nazzi, Bertoncini, & Mehler, 1998; Nazzi, Jusczyk, & Johnson, 2000). Our data, by supporting both a prosodically-based and a statistically-based account of early segmentation, contribute to the current shift in the field of language acquisition according to which both statistically-based and prosodic/phonological bootstrapping theories account for part of early language acquisition, from which it follows that the

central issue nowadays is to understand how the use of the two kinds of cues interacts in language acquisition.

With respect to the statistical cue of transitional probabilities (TPs), our results also confirm the early use of TPs by young French-learning infants. Indeed, the comparison of the outcomes of Experiments 1 and 3 shows that the syllabic effect is found when within-word TPs are low (as low as .125, Experiment 3) but not when they are 4 times (.5, Experiment 1) or 8 times higher (Nazzi et al., 2014). This finding first confirms prior results using the artificial language paradigm that Parisian French-learning infants are sensitive to TPs by 8 months of age (Mersad & Nazzi, 2012), just like English- and Dutch-learning infants of the same age (e.g., Saffran et al., 1996b; Johnson & Tyler, 2010). Second, as Pelucchi et al. (2009), it brings evidence of infants' use of TP information when processing complex, natural language stimuli. Moreover, and to the best of our knowledge, this is the first study that establishes an effect on infants' segmentation of manipulating the strength of the TP information present in the signal (since the comparison of Experiment 1 and 3 shows that manipulating TP strength affects the observation of syllabic segmentation).

Lastly, our results also show that both the rhythmic and the TP cues are used in combination by French-learning 8-month-olds, and that the relative strength of the two cues in the stimuli will determine the segmentation outcome (segmentation of a syllabic or bisyllabic word form). Similar effects had previously been found for stress-based English (Johnson & Jusczyk, 2001; Mersad & Nazzi, 2012; Saffran et al., 1996b; Thiessen & Saffran, 2003), and our results extend them for the first time to a syllable-based language, French. Note that a possible explanation, to be evaluated in future studies for the differences in performance found between Parisian and Canadian French infants might be related to differences in the relative strength of phonological (including rhythmic) cues and TP cues in these two dialects of French (see Nazzi et al., 2014 for a discussion regarding the possible role of increased word-final accentuation in Canadian compared to Parisian French).

To conclude, the present study brings several important findings to our understanding of early segmentation processes. First, Experiment 3 establishes early syllabic segmentation (by 8 months) in syllable-based French, supporting the early rhythmic-based segmentation hypothesis, one of the two segmentation procedures that have been proposed to be crucial at the time of emergence of segmentation abilities (Nazzi

et al., 2006). Second, taken together, the present findings show that the use of the syllabic unit is done in conjunction with the use of transitional probability (TP) information, and that the segmentation outcome depends on the relative strength of both cues: when TPs are low, the segmentation outcome is the syllabic unit (Exp. 3); when TPs are highest, as in Nazzi et al. (2014), the segmentation outcome is the bisyllabic word; when TPs are intermediate, no clear outcome is found, neither in terms of syllabic (Exp. 1) nor bisyllabic word (Exp. 2) segmentation. Future studies, using different kinds of methods (behavioral and/or ERPs), should keep exploring how infants use different cues to segment speech at different points in development and how the use of language-general statistical cues (TPs) and language-specific phonological cues (rhythmic units, phonotactic information, coarticulation, etc.) will lead to different trajectories of emergence of segmentation abilities according to the relative strength of these cues in different languages. In doing so, it will thus be important to expand the range of languages tested in the different rhythmic classes, taking care to set up experimental situations that allow researchers to dissociate the use of these various cues (e.g., TPs and rhythmic cues). This will in turn allow them to continue articulating the link, for word form segmentation, between the two influential theories for language acquisition explored here, namely the statistically-based and the prosodic/phonological bootstrapping theories.

Interim discussion

Knowing that French-learning 8-month-olds are able to segment syllabic units embedded in bisyllabic words in the right TP (transitional probability) context, the next study investigated segmentation at an earlier age: 6 months. As shown above, infants at 8 months are already sensitive to TPs and segmentation was facilitated when the TPs were at the lowest (Experiment 3). Using the same strength of TPs (rendering the syllabic units more salient), Experiment 4 first assessed whether French-learning 8-month-olds are able to segment monosyllabic words as observed in Gout (2001), but by reversing the order of presentation of the stimuli: instead of presenting words and then passages (as in Gout, 2001), we familiarized infants with passages and tested them on words (as in Goyet et al., 2013). The same stimuli were also used with 6-month-olds. Then, as done in Goyet et al. (2013), we explored whether 6-month-olds are able to segment syllables embedded in bisyllabic words (Experiments 5 & 6) and whether they can also segment bisyllabic words as whole units in the same experimental conditions (Experiment 7). The early

rhythmic segmentation hypothesis predicts earlier segmentation effects for syllables and embedded syllabic units compared to bisyllabic words.

2. French-learning 6-month-olds segment syllabic units

Nishibayashi, L.-L., Goyet, L., & Nazzi, T. (in press). Early speech segmentation in French-learning infants: monosyllabic words versus embedded syllables. *Language and Speech*.

*Experiment, table and figure numbers were changed from the original paper for coherence within this dissertation.

Abstract

Lexical acquisition relies on many mechanisms, one of which corresponds to segmentation abilities, that is, the ability to extract word forms from fluent speech. This ability is important since words are rarely produced in isolation even when talking to infants. The present study explored whether young French-learning infants segment from fluent speech the rhythmic unit of their native language, the syllable. Using the Headturn Preference Procedure and the passage word order, we explored whether these infants can segment monosyllabic words (at 6 and 8 months), syllables embedded in bisyllabic words (at 6 months), and bisyllabic words (at 6 months). Our results bring direct evidence in support of the early rhythmic segmentation hypothesis (Nazzi et al., 2006), by establishing syllabic segmentation both for monosyllabic words and embedded syllables at 6 months, while failing to find segmentation of bisyllabic words at the same age. They also indirectly extend to French previously reported effects of coarticulation, acoustic variation and infant-directed speech on segmentation found in English. Therefore, our study contributes to a better understanding of the similarities and differences in early segmentation across languages, thus to a better understanding of the mechanisms underlying segmentation.

2.1. Introduction

Infants are born with impressive perceptual skills to rapidly acquire the properties of their native language, such as its phonology, lexicon and syntax. The present study explores one of the mechanisms involved in learning a lexicon, namely the ability to segment, that is, to extract, the sound patterns of words from fluent speech. Word form segmentation constitutes a crucial step in lexical acquisition, because words mostly occur within sentences and only rarely in isolation (Aslin, 1993; Brent & Siskind, 2001), and a few findings established links between early segmentation and later language competence (Newman et al., 2006; Graf Estes et al., 2007; Kooijman et al., 2013). Many studies have explored the emergence of word form segmentation, using either behavioral methods (e.g., Headturn Preference Procedure, or HPP) or electrophysiological methods (e.g., Evoked-Response Potentials, or ERPs), and have established that this ability emerges around 8 months of age in infants learning English (Jusczyk & Aslin, 1995; Saffran et al., 1996b), Parisian French (Goyet, Nishibayashi & Nazzi, 2013; Mersad & Nazzi, 2012; Nazzi et al., 2014), Canadian French (Polka & Sundara, 2012; Shi, Marquis & Gauthier, 2006), Dutch (Houston et al., 2000; Kooijman et al., 2005, 2013) and German (Höhle & Weissenborn, 2003). The goal of the present study was to investigate the early use, in French-learning infants, of the rhythmic unit of French, namely, the syllable, for segmenting monosyllabic words and syllables that are embedded in bisyllabic words.

Previous research has established that during the first year of life, infants use many subtle linguistic cues present in the signal to identify boundaries between words. These cues include transitional probabilities (TPs, referring to distributional regularities in the order of syllables in the speech signal: Johnson & Jusczyk, 2001; Mersad & Nazzi, 2012; Saffran et al., 1996b, 1999), the rhythmic unit of the native language (Curtin, Mintz & Christiansen, 2005; Goyet et al., 2010, 2013; Jusczyk, Houston & Newsome, 1999a; Nazzi et al., 2006), prosodic boundaries (Gout, Christophe & Morgan, 2004; Seidl & Johnson, 2006), co-articulatory cues (Johnson & Jusczyk, 2001), allophonic information (Jusczyk, Hohne & Bauman, 1999b), phonotactic information (Gonzalez-Gomez & Nazzi, 2013; Mattys et al., 1999; Mattys & Jusczyk, 2001a), known words (Bortfeld et al., 2005; Mersad & Nazzi, 2012) and pitch accent (Nazzi et al., 2005). The hypothesis regarding the use of the rhythmic unit for segmentation, on which the present study focuses, is linked to “prosodic or phonological bootstrapping” theories (Morgan & Demuth, 1996) which claim

that the speech signal contains many acoustic/prosodic cues that facilitate infants' learning of the properties of their native language, such as its basic rhythm (Nazzi, Bertoncini & Mehler, 1998), its lexicon and some properties of that lexicon (Gleitman & Wanner, 1982; Jusczyk et al., 1993a) or its syntactic structure (Hirsh-Pasek et al., 1987). Accordingly, the early rhythmic segmentation hypothesis states that young infants use the rhythmic unit of their native language to segment the continuous speech stream (Nazzi et al., 2006). Given that languages have different rhythmic units (the trochaic or strong-weak stress unit in stress-based languages such as English, Dutch and German; Pike, 1945; the syllable in syllable-based languages such as French, Spanish, Catalan and Italian; Abercrombie, 1967), this hypothesis predicts that there should be cross-linguistic differences in the way segmentation abilities emerge during development.

Several studies investigated the early use of the trochaic unit (a sequence of syllables in which the first syllable is stressed) for segmentation in infants learning stress-based languages. In particular, Jusczyk et al. (1999a) conducted a series of 15 HPP experiments to explore the segmentation of bisyllabic words by English-learning infants. Depending on the experiments, infants were tested in two different ways: either by familiarizing them with 2 lists of repeated trochaic (strong-weak) or iambic (weak-strong) bisyllabic words and testing them with 2 passages containing the target words versus 2 passages containing novel words (word-passage order); or by familiarizing infants with 2 passages each containing a target word and testing them on lists of repetitions of the 2 target words versus lists of repetitions of 2 novel words (passage-word order). At 7.5 months, in both orders, English-learning infants segment and recognize trochaic words while not recognizing as targets the sole stressed syllables of the trochaic words. This suggests that these infants do not extract the initial stressed syllables of trochaic words independently. In contrast, English-learning infants fail to segment iambic words at 7.5 months. At that age, when familiarized with passages containing iambic words (e.g., *guiTAR*), they segment and recognize their sole stressed syllables (e.g., *TAR*), and when that syllable is consistently followed by the same weak syllable (e.g., *is*), they extract a trochaic sequence consisting of the final stressed syllable of the iambic word and the following weak syllable (e.g., *TARis*). In contrast, at 10.5 months, English-learning infants segment iambic words and stop segmenting the stressed syllables of these iambic words individually or in combination with a consistently following weak syllable. Taken together, these findings suggest that at the younger age

(7.5 months), infants extract trochaic units whether or not they correspond to actual words, as long as the syllables in the trochaic units consistently co-occur in the signal. At the later age (10.5 months), they appear able to combine distributional (and probably coarticulation) information to segment word forms that do not conform to the rhythmic unit of English. Convergent findings were obtained for Dutch-learning infants at 9 months using HPP (Houston et al., 2000) and at 7 and 10 months using ERPs (Kooijman et al., 2005, 2013). The results on English- and Dutch-learning infants are thus compatible with the idea that the trochaic unit is used for early word form segmentation by infants learning stress-based languages, suggesting specialization to the native language in segmenting the speech stream during the first half of the first year of life.

What about early segmentation in syllable-based languages like French, and the early use of the syllabic unit for segmentation in infants learning such languages? Two strategies have been employed to address this question, looking either at the segmentation of monosyllabic words or comparing the segmentation of bisyllabic words versus syllables embedded in bisyllabic words. Regarding the segmentation of monosyllabic words in French, Gout (2001), using HPP and the word-passage order, found that French-learning 7.5-month-olds could segment monosyllabic words, but could not replicate this finding in 10.5-month-old infants. These mixed findings require further exploration of this issue, in particular in light of recent evidence of monosyllabic word segmentation in Spanish-learning monolinguals, Catalan-learning monolinguals and Spanish-Catalan bilinguals at both 6 and 8 months of age (Bosch et al., 2013), using HPP but the passage-word order. Experiment 1 of the present study will explore whether such early effects can also be found in French in the passage-word order (see below for further discussion of the importance of order effects).

While the above studies provide some evidence of early segmentation of monosyllabic words in syllable-based languages, it has been argued that such evidence is ambiguous when it comes to the issue of the syllable as a basis of segmentation because the syllabic and lexical levels are confounded in monosyllabic words (and because stressed syllables can also constitute a trochaic feet in English, which can be segmented as early as 7.5 months, Jusczyk & Aslin, 1995). Nazzi et al. (2006) pointed out that stronger evidence of syllabic segmentation would be provided by data showing that infants segment individual syllables embedded in multisyllabic words before (in developmental time or in the order of processing) they segment whole bisyllabic words. In this context,

what do we know, first, regarding whole word bisyllabic segmentation in French? In a first study, using HPP and the word-passage order, Nazzi et al. (2006) found an emergence of bisyllabic word segmentation between 12 and 16 months of age, potentially revealing a delay in the segmentation of words larger than the syllable in French-learning infants. However, more recent studies found earlier evidence of bisyllabic word segmentation, by 12 months using ERPs (Goyet et al., 2010), by 8 months using HPP and an artificial language paradigm (Mersad & Nazzi, 2012), and by 8 months using HPP in a population of infants learning Canadian French (Polka & Sundara, 2012). This later finding led to a further reevaluation of bisyllabic word segmentation in (European) French-learning infants using HPP and natural language stimuli, which revealed that bisyllabic word segmentation can be found at 8 months in the passage-word order, but not before 16 months in the word-passage order, even when using the same stimuli (Nazzi, Mersad, Sundara, Iakimova, & Polka, 2014). The authors proposed that this order effect in French-learning infants might be a result of the use of syllabic segmentation: if infants go through an initial process of segmenting syllables independently, they will need to use distributional information in order to form bisyllabic units. In the passage-word order, this information is provided to infants during the familiarization phase, and might thus be readily available at the test phase; on the contrary, in the word-passage order, this information gradually becomes available during the test phase, which might render the observation of a segmentation effect more difficult. Note that while such order effects should not be found for monosyllabic words cross-linguistically, nor for trochaic words in stress-based languages (since the segmentation of both types of words does not require distributional information), they might be found for early segmentation of iambic words in stress-based languages, a prediction that will have to be tested in future studies. In summary, the studies on French using bisyllabic words show that these words can be segmented as early as 8 months of age, in conditions in which infants have access to distributional information supporting the co-occurrence of these two syllables.

In this context, support for the early rhythmic segmentation hypothesis in syllable-based French would require that French-learning infants segment syllabic units by or before 8 months, and/or that in segmenting bisyllabic words, they go through an initial processing stage of segmenting individual syllables. In HPP experiments using the word-passage order, in which infants were familiarized with individual syllables and then tested on passages containing or not these syllables embedded in target bisyllabic words,

evidence of syllabic segmentation had only been found at 12 months of age (Nazzi et al., 2006). However, more recent evidence using the passage-word order found such evidence as early as 8 months of age (Goyet et al., 2013). In that study, infants were familiarized with passages containing either 2 target bisyllabic words (each repeated 4 times) or 8 target bisyllabic words (each presented once), and within each passage, all target words shared a target syllable (thus repeated 8 times in both conditions). Moreover, syllables preceding and following the target words were all different. These manipulations were made so that in the 2 target word condition, TPs (transitional probabilities) between syllables around the target syllables remained informative of the fact that the target syllables were part of bisyllabic words, but about half less than in “classic” studies in which each passage only contained one repeated bisyllabic word. However, in the 8 target word condition, TPs were uninformative of the fact that the target syllables were part of bisyllabic words, so that infants should process them as syllabic units. When tested on their recognition of the target syllables, infants succeeded in the 8 target word condition but not in the 2 target word condition. Therefore, when distributional information (TPs) is neutralized, 8-month-old infants appear to be segmenting separately syllables embedded in bisyllabic words. Moreover, in the 2 target word condition, 8-month-old infants were also tested on their recognition of the target bisyllabic words, and failed to do so. This is important because it establishes that in the 8 target word condition in which infants segmented the individual target syllable, they could not have segmented the 8 target words first and then accessed the common syllable, since they could not even segment the bisyllabic words in the 2 target word condition. Therefore, Goyet et al. (2013) establishes that French-learning 8-month-olds segment individual syllables in a first segmentation step. It further suggests that in order to form bisyllabic units, they need the presence of consistent distributional information to attach the consecutive syllables in the speech stream, as was the case in Nazzi et al. (2014) in which bisyllabic word segmentation was found, but was not the case in Goyet et al. (2013) in which it was not found. Experiments 2 and 3 of the present study will use the 8 target word condition of Goyet et al. (2013) to probe syllabic segmentation in younger, 6-month-old infants.

To summarize the goal of the present study, Experiment 4 was conducted, first, to assess French-learning 8-month-olds’ abilities to segment monosyllabic words in the passage-word order, in order to extend the finding of Gout (2001) using the word-passage order. Second, it sought to determine whether these abilities can be found in infants as

young as in Bosch et al. (2013), that is, at 6 months. Experiments 5 and 6 then explored whether French-learning 6-month-olds can segment syllables embedded in bisyllabic words in order to confirm the rhythmic-based segmentation hypothesis (Nazzi et al., 2006). Lastly in Experiment 7, we tested the segmentation of whole bisyllabic words, to investigate the relative order of emergence of segmentation of syllabic units versus segmentation of bisyllabic words as found at 8 months in Nazzi et al. (2014). In all experiments, we used HPP and the passage-word order, with 30 (Experiments 4 and 5) or 45 seconds (Experiments 6 & 7) of familiarization to each passage. We chose to use 30s familiarization times in our first two experiments because this is the duration under which the segmentation of bisyllabic words (Nazzi et al., 2014) and of syllables embedded in bisyllabic words (Goyet et al., 2013) was found for French-learning 8-month-olds. In Experiment 4, infants were familiarized with two passages, each containing 8 repetitions of a monosyllabic word, and then tested on whether they had segmented those monosyllabic words by being presented with the two target monosyllabic words versus two control monosyllabic words.

2.2. Experiment 4: monosyllabic word segmentation at 8 and 6 months

2.2.1. Method

Participants

Forty healthy full-term infants were included, 20 (12 females and 8 males) 8-month-olds (mean age: 8 months and 10 days; range: 8 months and 1 day to 8 months and 28 days) and 20 (9 females and 11 males) 6-month-olds (mean age: 6 months and 10 days; range: 6 months to 6 months and 27 days). Nine additional infants were tested but not included due to fussiness (5) or crying (4). All the infants were from monolingual French-speaking families. All parents gave informed consent before participation and completed an information sheet.

Stimuli

Four monosyllabic CV words (/di/, /po/, /te/, /gu/) were selected (see Table 1.1.). As in previous research on this topic, these target words were nouns with relatively low frequencies, as given in the adult database LEXIQUE 2 (New et al., 2004, given per 1 million occurrences, and calculated over a base of 31 million occurrences): /di/ = 4.86 (*dit*

[a said]), /po/ = 32.3 (*pot* [pot]), /te/ = 44.19 (*thé* [tea]), /gu/ = 124.8 (*goût* [taste]). Moreover, they were not listed in the French CDI (Kern, 2003).

For each target word, an 8-sentence passage was created for the familiarization phase. The target words appeared either towards the beginning (4 times) or towards the end (4 times) of the sentences (Appendix 1.1). Mean number of syllables per sentence was 10. To prevent infants from relying on transitional probabilities to segment words, syllables preceding and following the target words were always different so that no specific syllabic sequences were repeated within the passages.

Table 1.1. Target syllables (presented at test) and words corresponding to/containing the target syllables (presented during familiarization) used in Experiments 1-4.

	Words in the familiarization passages	Targets at test
Exp. 4	dit [a said]	/di/
	pot [pot]	/po/
	thé [tea]	/te/
	goût [taste]	/gu/
Exp. 5 & 6	dîner [dinner], dizain [dizain], divan [couch], dito [ditto]; caddie [caddy], bandit [bandit], taudis [slum], radis [radish]	/di/
	poney [foal], pommeau [knob], pochon [pouch], potin [gossip]; capot [car hood], dépôt [deposit], topo [topo], repos [rest]	/po/
	télé [TV], tesson [shard], têtu [stubborn], téton [nibble]; cité [city], pâté [block], synthé [synth], comté [county]	/te/
	goulot [neck], goujon [stud], gourou [guru], gouda [gouda]; dégoût [disgust], ragout [stew], cagou [kagu], bagou [fluency of speech]	/gu/
Exp. 7	bandit [bandit]	/bādi/
	capot [car hood]	/kapo/
	jeté [a throwing]	/ʒøte/
	ragoût [stew]	/ragu/

The sentences were recorded by a French-native female talker in a sound-attenuated booth. She was asked to produce the sentences with mild IDS (infant-directed speech). The passages lasted 20 seconds each. For each syllable, the same talker also produced a list of 20 isolated occurrences for the test phase, which she produced with some variations to avoid infants' boredom and also to evaluate recognition of the targets in a condition with some acoustic variability. The four lists lasted 20 s each. Mean values of syllable duration, intensity and pitch for passages and lists are reported in Table 1.2.

Table 1.2. Acoustic measurements of target syllables in passages and in lists used in Experiments 4-7.

	words in passages					words/syllables in lists			
	Exp. 4	Exp. 5 & 6		Exp. 7		Exp. 4	Exp. 5 & 6	Exp. 7	
	word	initial syllable	final syllable	initial syllable	final syllable	word	syllable	initial syllable	final syllable
Duration (ms)	165	145	161	148	146	358	321	227	273
Intensity (dB)	74.4	74.4	74.8	75,5	75	76.1	74.7	75,1	74,6
Pitch (Hz)	238	215	232	210	228	204	216	226	225

Procedure, apparatus and design

The experiment was conducted in a sound-attenuated booth, which contained a three-sided test booth made of pegboard panels. The test booth had a red light and loudspeakers (Sony xs-F1722) mounted on each of the side panels and a green light mounted on the central panel. A video camera was situated directly below the center light to monitor infants' behavior. A PC computer terminal (Dell Optilex), audio amplifier (Marantz PM4000), TV screen and response box were located outside the sound-attenuated room. The stimuli were stored in digitized form on the computer and were delivered by the loudspeakers via the amplifier. The response box, which was connected to the computer, was equipped with 3 buttons. The box was controlled by an observer, outside the sound-attenuated booth, who watched the video of the infant on the TV screen and pressed the buttons according to the direction the infant's headturns, thus starting and stopping the flashing of the lights and the presentation of the sounds. The observer and the infant's caregiver wore earplugs and listened to masking music over tight-fitting headphones, which prevented them from hearing the stimuli. Information about the direction and duration of the headturns/orientation times were stored in a data file on the computer.

The variant of HPP set up by Jusczyk and Aslin (1995) was used in the present experiment. Each infant was held on a caregiver's lap and the caregiver was seated in a chair at the center of the test booth. Each trial began with the green light on the center panel blinking until the infant had oriented in that direction. Then the center light was extinguished and the red light above the loudspeaker on one of the side panels began to flash. When the infant made a turn of at least 30° in the direction of the loudspeaker, the

stimulus for that trial was played, the red light continuing to flash for the entire duration of the trial. Each stimulus was played to completion or stopped immediately after the infant failed to maintain the 30° headturn for two seconds. If the infant turned away from the red light for less than two seconds and then turned back again, the trial continued but the time spent looking away was not included in the orientation time. Thus, the maximum orientation time for a given trial was the duration of the entire speech sample (20s). If for a trial, the infant's orientation time was shorter than 1.5 seconds, the trial was immediately replayed from the beginning and the initial orientation time was discarded.

Each experimental session began with a familiarization phase in which infants heard two passages on alternating trials until they accumulated 30 s of orientation times to each. When the infants reached the familiarization criterion for one passage, the second passage continued to be presented until its criterion was also reached. The side of the loudspeaker from which the stimuli were presented was randomly varied from trial to trial. The test phase began immediately after the familiarization criterion was reached. It consisted of three test blocks, in each of which the four lists of isolated syllables were presented. The order of the lists within each block was randomized.

Each infant was familiarized with two passages and tested with the 2 target and the 2 control syllables. Each syllable was used as target for half of the infants and as control for the other half.

2.2.2. Results and Discussion

Mean orientation times (OTs) to the lists containing the target versus the control monosyllabic words were calculated for both ages (see Figure 1.2., left panel). A 2-way ANOVA with the between subject factor age (6 vs. 8 months of age) and the within-subject factor of familiarity (target vs. control) was conducted. The effect of familiarity was significant ($F(1,38) = 22.1$, $p = .00003$, $\eta^2_p = .368$) indicating that infants had a preference for target ($M = 7.85$ s, $SD = 2.24$) over control ($M = 6.65$ s, $SD = 2.03$) syllables. Moreover, 31 of the 40 infants oriented longer to the familiar lists (binomial test, $p = .0003$). The effect of age and the familiarity x age interaction failed to reach significance (all F s < 1). Although the factor of familiarity did not interact with the factor of age, we conducted planned comparisons at both ages that confirmed a familiarity effect at both 6 ($F(1,18) = 12.24$, $p = .003$, $\eta^2_p = .405$) and 8 ($F(1,18) = 10.29$, $p = .005$, $\eta^2_p = .364$) months.

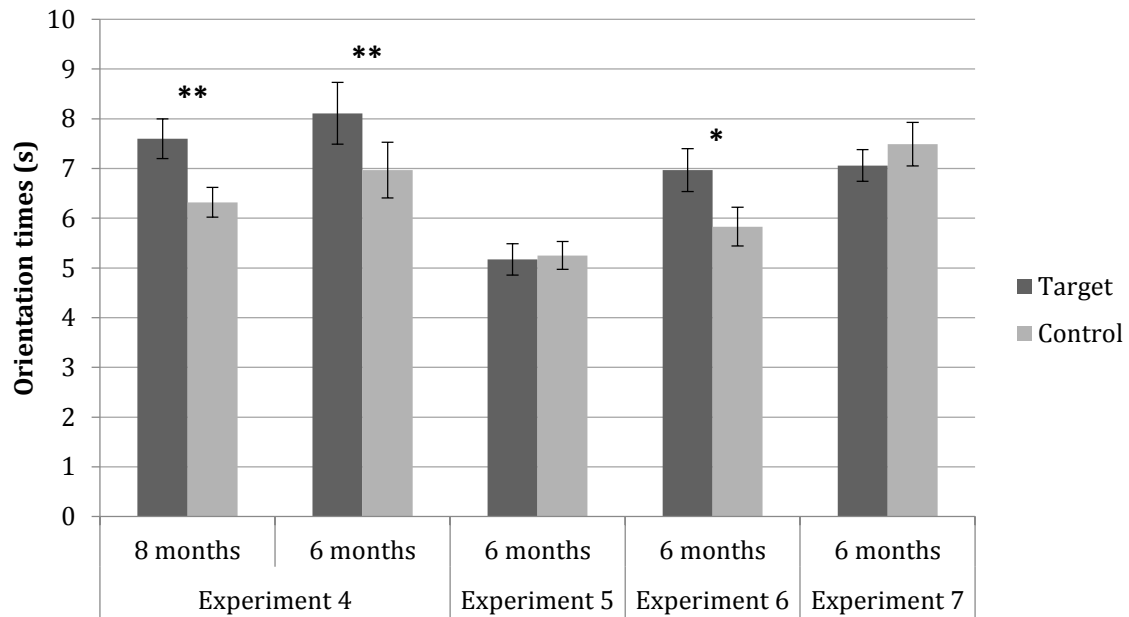


Figure 1.2. Mean orientation times (and SEs) to target vs. control syllables in Experiments 4-7 (** = $p < 0.01$; * = $p < 0.05$).

By familiarizing French-learning infants for 30 seconds with passages and testing them with lists of repeated target vs. control words, we demonstrated syllabic segmentation effects at both 8 and 6 months of age, thus earlier than previous reports for French (Goyet et al., 2010, 2013; Nazzi et al., 2006, 2014). Our results extend from Spanish and Catalan to French, the finding that 6-month-olds learning a syllable-based language are able to segment monosyllabic words (Bosch et al., 2013). To further explore syllabic segmentation at 6 months in French, in a situation in which the syllabic level is distinct from the lexical level, the next experiment replicated Experiment 3 of Goyet et al. (2013), which demonstrated segmentation of syllables embedded in bisyllabic words in French-learning 8-month-olds. Infants were familiarized for 30 seconds with two passages, each containing 8 different bisyllabic words that had in common one target syllable (in word-initial position for half of the words, word-final position for the other half), and then tested on whether they had segmented those syllables by being presented with the two target syllables, and two control syllables.

2.3. Experiment 5: syllabic segmentation at 6 months

2.3.1. Method

Participants

Twenty healthy full-term 6-month-olds were included (10 females and 10 males; mean age: 6 months and 15 days; range: 6 months and 2 days to 7 months and 6 days). Three additional infants were tested but not included due to fussiness (1) or crying (2). All the infants were from monolingual French-speaking families. All parents gave informed consent before participation and completed an information sheet.

Stimuli

We used the same four syllables as in Experiment 4, which have relatively low frequencies, as given in the adult database LEXIQUE 2, in the initial and final positions of French bisyllabic words: /di/ (initial position: 20.47; final position: 3.06); /po/ (initial position: 1.55; final position: 13.65); /te/ (initial position: 7.79; final position: 8.56) and /gu/ (initial position: 3.08; final position: 6.72). For each syllable, eight bisyllabic target words that start (4) or end (4) with that syllable were also chosen for their relatively low frequencies (see Table 1.1.).

As in Experiment 4, an 8-sentence passage was created for the familiarization phase for each target syllable. Again, the target words appeared towards the beginning (4 times) or the end (4 times) of the sentences, and syllables preceding and following the target words were always different (Appendix 1.2.).

The female talker of Experiment 4 recorded the passages and the four lists of 20 target syllables following the same recording instructions. Mean values of syllable duration, intensity and pitch for passages and lists are reported in Table 1.2.

Procedure, apparatus and design

The procedure, apparatus and design were identical to Experiment 4.

2.3.2. Results and Discussion

Mean OTs were calculated for the lists containing the target versus the control syllables (see Figure 1.2., second panel). A paired t-test failed to show a significant difference in OTs to target ($M = 5.17$ s, $SD = 1.41$) and control ($M = 5.25$ s, $SD = 1.25$) syllables ($t(19) = .101$, $p = .75$). Moreover, only 8 of the 20 infants oriented longer to the target syllables (binomial test, $p = .503$).

Experiment 5 fails to provide evidence that French-learning 6-month-olds segment syllables that are embedded in bisyllabic words. These results show that segmenting syllables in bisyllabic words is more demanding than segmenting monosyllabic words (Experiment 4). However, before concluding that French-learning 6-month-olds fail at segmenting syllables in bisyllabic words, contrary to 8-month-olds who succeed in the exact same conditions (Goyet et al., 2013), Experiment 6 was conducted. It replicated Experiment 5 with an increased familiarization time of 45s (rather than 30s) to each passage, as done in many studies using the passage-word order (English: Jusczyk & Aslin, 1995; Jusczyk et al., 1999a; Spanish, Catalan, Spanish/Catalan: Bosch et al., 2013; Canadian French: Polka & Sundara, 2012). This might facilitate segmentation by giving infants more opportunities to hear in context and segment the target syllables.

2.4. Experiment 6: syllabic segmentation at 6 months (longer familiarization)

2.4.1. Method

Participants

Twenty healthy full-term 6-month-olds were included (11 females and 9 males; mean age: 6 months and 12 days; range: 5 months and 24 days to 7 months and 10 days). Seven additional infants were tested but not included due to fussiness (1), crying (4), or a segmentation index (defined as the difference between the mean orientation times to the lists of target and control syllables) more than 2 SDs above or below the group mean (2). All the infants were from monolingual French-speaking families. All parents gave informed consent before participation and completed an information sheet.

Stimuli, procedure, apparatus and design

The stimuli, procedure, apparatus and design were identical to Experiment 5. The only difference was that familiarization time was 45 s for each passage.

2.4.2. Results and Discussion

Mean OTs were calculated for the lists containing the target versus the control syllables (see Figure 1.2., third panel). A paired t-test showed a significant preference for target ($M = 6.97$ s, $SD = 1.93$) over control ($M = 5.83$ s, $SD = 1.75$) syllables ($t(19) = 9.98$, $p = .005$, Cohen's $d = .619$), with 16 of the 20 infants having longer OTs to the target syllables (binomial test, $p = .012$). To compare Experiments 5 and 6, a 2-way ANOVA with

the factors of experiment and familiarity (target vs. control) was conducted. The effect of familiarity was significant ($F(1,38) = 5.99, p = .019, \eta^2_p = .136$) indicating that infants had a preference for target ($M = 6.07$ s, $SD = 1.90$) over control ($M = 5.54$ s, $SD = 1.53$) syllables. The effect of experiment was also significant ($F(1,38) = 6.63, p = .014, \eta^2_p = .149$), infants having longer looking times in Experiment 6 than in Experiment 5. Importantly, the familiarity x experience interaction was significant ($F(1,38) = 7.85, p = .008, \eta^2_p = .171$), confirming that infants behaved differently in the two experiments, successfully segmenting only with the longer familiarization (Experiment 6). Therefore, the present findings are the first to establish syllabic segmentation at 6 months of age, earlier than previously found for French (Goyet et al., 2010, 2013; Nazzi et al., 2006, 2014), even when the syllabic level does not match the lexical level.

To further investigate the relative order of emergence during development of segmentation of syllabic units (at 6 months in the present study) versus segmentation of bisyllabic words (found at 8 months in Nazzi et al., 2014), we conducted a new experiment with 6-month-olds testing bisyllabic word segmentation. Since successful evidence of segmentation of syllables embedded in bisyllabic words was found in the passage-word order for a familiarization duration of 45 seconds (Experiment 6) but not 30 seconds (Experiment 5) to each passage, Experiment 7 tested bisyllabic word segmentation in the same passage-word order using the same (easier) 45s duration of familiarization.

2.5. Experiment 7: bisyllabic word segmentation at 6 months

2.5.1. Method

Participants

Twenty healthy full-term 6-month-olds were included (8 females and 12 males; mean age: 6 months and 8 days; range: 6 months to 6 months and 21 days). Three additional infants were tested but not included due to crying (2) or a segmentation index (defined as the difference between the mean orientation times to the lists of target and control syllables) more than 2 SDs above or below the group mean (1). All the infants were from monolingual French-speaking families. All parents gave informed consent before participation and completed an information sheet.

Stimuli

We selected four bisyllabic words containing the same four syllables as in Experiment 4 (see Table 1.1.), words with relatively low frequencies as given in the adult database LEXIQUE 2: /bãdi/ = 4.59 (*bandit* [bandit]); /kapo/ = 7.23 (*capot* [car hood]); /ʒøte/ = 1.62 (*jeté* [a throwing]) and /ragu/ = 3.65 (*ragoût* [stew]). For each word, an 8-sentence passage was created for the familiarization phase. Again, the target words appeared either towards the beginning (4 times) or towards the end (4 times) of the sentences, had a mean number of syllables per sentence of 11, and syllables preceding and following the target words were always different (Appendix 1.3).

The sentences were recorded in a sound-attenuated booth by the same French-native female talker as in Experiments 4 – 6. She was asked to produce the sentences with mild IDS (infant-directed speech). The passages lasted 20 seconds each. For each word, the same talker also produced a list of 20 isolated occurrences for the test phase. Mean values of syllable duration, intensity and pitch for passages and lists are reported in Table 1.2.

Procedure, apparatus and design

The procedure, apparatus and design were similar to Experiments 4 – 6.

2.5.2. Results and discussion

Mean OTs were calculated for the lists containing the target versus the control words (see Figure 1.2., right panel). A paired t-test failed to show a significant preference for target ($M = 7.06$ s, $SD = 1.44$) over control ($M = 7.51$ s, $SD = 1.93$) words ($t(19) = -1.24$, $p = .23$), with 6 of the 20 infants having longer OTs to the target words (binomial test, $p = .115$). The present findings fail to establish bisyllabic word segmentation at 6 months of age, under the same test conditions as segmentation of embedded syllables was found in Experiment 6.

To compare Experiments 6 and 7, a 2-way ANOVA with the factors of experiment and familiarity (target vs. control) was conducted. The effect of familiarity was not significant ($F(1,38) = 1.79$, $p = .19$) indicating that infants had no preference for targets ($M = 7.01$ s, $SD = 1.68$) over controls ($M = 6.67$ s, $SD = 2.01$). The effect of experiment was not significant ($F(1,38) = 3.18$, $p = .08$), infants having equal looking times in Experiment 7 ($M = 7.29$ s, $SD = 1.70$) and Experiment 6 ($M = 6.40$ s, $SD = 1.91$). Importantly, the familiarity x experience interaction was significant ($F(1,38) = 9.6$, $p = .004$, $\eta^2_p = .202$),

confirming that infants behaved differently in the two experiments, successfully segmenting only with the embedded syllable (Experiment 6). Therefore, the present findings provide new evidence regarding the relative developmental order of emergence of segmentation of syllabic units and bisyllabic words in French, establishing an advantage for syllables.

2.6. General Discussion

The main goal of the present segmentation study, using HPP, was to explore French-learning infants' ability to segment syllables from fluent speech in the passage-word order (which provided early segmentation results in recent studies in this language, Goyet et al., 2013; Nazzi et al., 2014), contrasting two conditions: one in which the syllables corresponded to monosyllabic words, and one in which they were embedded in bisyllabic words. Our main goal was to determine French-learning infants' early use of the rhythmic unit of their native language, the syllable, to segment fluent speech. Our findings establish that at 6 months of age, the earliest age at which segmentation has ever been reported in any language, French-learning infants are able to segment both the monosyllabic words (Exp. 4) and the embedded syllables (Exp. 6), therefore demonstrating the early use of syllabic units for segmentation abilities in this language. Moreover, at the same age, and under similar test conditions, we failed to find evidence of bisyllabic word segmentation in French-learning infants (Exp. 7).

The above pattern of results contributes to supporting the early rhythmic segmentation hypothesis stating that infants initially use the rhythmic unit of their native language (the syllable in French) to segment the continuous speech stream (Nazzi et al., 2006) in two ways. First, it shows that at 6 months of age, syllabic units can be segmented by French-learning infants when they correspond to words (Exp. 4), but more importantly also when they are embedded in a longer bisyllabic word (Exp. 6), a condition in which the syllabic and lexical levels are distinct. This extends to 6 months a similar finding by Goyet et al. (2013) with 8-month-olds. Given that at 6 months, Experiment 7 failed to find evidence of bisyllabic segmentation, the present studies confirm the prediction that the ability to segment syllabic units emerges before the ability to segment longer units. Second, the comparison of Experiments 6 and 7 establishes that the segmentation of the embedded syllables in Experiment 6 cannot have been the by-product of the segmentation

of the 8 bisyllabic words that contained these target syllables, since if it were the case, infants should have segmented the target bisyllabic words in Experiment 7. This pattern of findings thus establishes that in terms of processing, French-learning 6-month-olds have access to the rhythmic unit of their native language before accessing larger units. Therefore, the precedence of syllabic segmentation over bisyllabic word segmentation both in terms of developmental and processing time found here with 6-month-olds confirms the predictions of the early rhythmic segmentation hypothesis for French (Nazzi et al., 2006).

The present findings also demonstrate that the emergence of segmentation abilities is not delayed in French, contrary to what was suggested by the first studies having explored segmentation in this language (Gout, 2001; Nazzi et al., 2006). Taken together with more recent studies (for Parisian French: Gonzalez-Gomez & Nazzi, 2013; Goyet et al., 2013; Nazzi et al., 2014; for Canadian French: Polka & Sundara, 2012), they suggest the emergence of bisyllabic word segmentation between 6 and 8 months of age while pushing down to 6 months the appearance age of syllabic segmentation. It thus appear that using the passage-word order in French allows the observation of early segmentation effects in French, sometimes earlier than using the word-passage order (as found for bisyllabic word segmentation, Nazzi et al., 2014).¹ Furthermore, the present results add to the findings of monosyllabic word segmentation at 6 months in two other syllable-based languages, Spanish and Catalan (Bosch et al., 2013). However, note that in the present study, we only found familiarity effects, while Bosch et al. (2013) observed a switch from a familiarity to a novelty effect between 6 and 8 months. This change was interpreted in relation to the Hunter and Ames (1988) model as evidence that the task was easier for the older infants. Why we did not find this developmental effect remains to be further explored. Yet, one possibility is that the development of segmentation abilities

¹ Nazzi et al. (2014) proposed that the passage-word order advantage found for bisyllabic word segmentation might result from infants processing TP information during familiarization and thus having access to it right from the beginning of the test phase, while, in the word-passage order, it emerges over the trials of the test phase. Note also that there are other possible reasons that disadvantage the word-passage order. For example, in the word-passage order, infants have to go through two simultaneous steps during the test phase (segmentation the passages; matching of the segmentation outcome to what was heard during familiarization), while during the test phase in the passage-word order, infants “only” have to match the isolated words to the segmentation outcomes from the familiarization phase. Moreover, in the word-passage order, infants hear 4 passages instead of 2 in the passage-word order, so that they have to process more syllables/words. Future studies will have to explore more systematically order effects in French and other languages, for different types of words, in order to clarify how these order effects reflect availability and use of cues for segmentation. Note however that the passage-word order constitutes a more ecological situation since words are rarely produced in isolation (Brent & Siskind, 2001) and infants have to segment speech streams to extract their first word forms. In that sense, results obtained in the passage-word order might provide a better reflection of early segmentation abilities.

does not follow the same trajectory/timing in French versus Spanish/Catalan. Another non-exclusive possibility is that the stimuli used in our study were recorded in a less pronounced infant-directed speech (as attested by shorter durations and lower pitch in Table 1.2.), which might have made the task slightly more difficult. This possibility is supported by studies having shown a preference for infant-directed speech (Fernald & Kuhl, 1987) and starting to show facilitating effects of infant-directed speech on early language processing (segmentation: Singh et al., 2009; Thiessen, Hill & Saffran, 2005; word learning: Graf Estes & Hurley, 2013).

Importantly, our findings also reveal differences in the ability to segment monosyllabic words and embedded syllables, the former appearing to be easier to segment than the latter. This is demonstrated by the fact that while infants only needed 30s of familiarization with the passages containing the monosyllabic words, they needed 45s of familiarization with the passages containing the syllables embedded in bisyllabic words (although the main segmentation effect in the joint analysis of Experiments 5 and 6 suggests the possibility that some infants succeeded to segment in the 30s condition, even though as a group, the infants failed in that condition). What could explain these differences? Since coarticulation has been found to affect segmentation (Johnson & Jusczyk, 2001), one possibility is that syllables in bisyllabic words are more co-articulated than syllables corresponding to monosyllabic words, and that co-articulation made the recognition more difficult for the more co-articulated syllables. In addition, this effect might have been increased by the fact that half of the embedded syllables corresponded to the first syllables of the words, and half corresponded to the final syllables, with the syllables in initial position being shorter and having lower pitch than both the syllables in final syllables and the syllables corresponding to monosyllabic words (see acoustic measurements in Table 1.2.). Therefore, infants tested with embedded syllables might have had to deal with increased acoustic variation between the different instantiations of the syllables, which is also known from studies on English-learning infants to negatively affect early segmentation (Houston & Jusczyk, 2000; Singh et al., 2009).

In conclusion, the present study brings new evidence in support of the early rhythmic segmentation hypothesis (Nazzi et al., 2006), by establishing syllabic segmentation both for monosyllabic words and embedded syllables, but not bisyllabic words, at 6 months in infants learning a syllable-based language, French (contrary to the trochaic unit segmented by young infants learning stress-based languages). They also

indirectly support previous effects of coarticulation, acoustic variation and infant-directed speech previously reported to affect segmentation in English-learning infants. Therefore, our study contributes to a better understanding of the similarities and differences in early segmentation across languages, thus to a better understanding of the mechanisms underlying segmentation.

Interim Discussion

Taken together, the two series of experiments reported so far (Goyet et al., 2013; Nishibayashi et al., in press) provide evidence of early segmentation abilities in French-learning infants. In summary, 8-month-olds are able to extract bisyllabic words as whole words and also single syllables that either constitute monosyllabic words or that are part of bisyllabic words. Moreover, we found that 6-month-olds are also able to segment monosyllabic words and if given more time during familiarization (30s → 45s) they can also extract syllables embedded in bisyllabic words. However, they were not able to extract bisyllabic words as whole units under the same testing conditions. This suggests that French-learning infants begin to segment speech with syllabic units, hence, by using the rhythmic unit of their native language. Then, probably by acquiring – and learning to combine – the suprasegmental (e.g., vowel lengthening generally interpreted as word offsets in French and word onsets in English), segmental (e.g., phonotactics) and subsegmental (e.g., coarticulation) segmentation cues of their native language and statistical cues (TPs), infants become able to segment bisyllabic words as whole units. This pattern of segmentation (syllabic unit → bisyllabic word) is in line with Nazzi et al. (2006) rhythmic segmentation hypothesis postulating that infants do segment speech according to their native language rhythmic unit, which is the trochaic unit in stress-based languages (e.g., Jusczyk & Aslin, 1995 for English) and the syllable in syllable-based languages (e.g., the present study for French). Our studies (Goyet et al., 2013; Nishibayashi et al., in press) also showed that there is a sensitivity to TPs, at least as early as 8 months of age and also suggested a sensitivity to coarticulation cues at 6 months. Therefore, very early on, infants appear to combine different segmentation cues. Further studies are needed to explore infants' ability to combine multiple segmentation cues and to determine if and how this combined use changes during development.

The rhythmic bootstrapping hypothesis (Nazzi et al., 2006) postulates that infants acquire their native language rhythmic unit to segment speech. However, while English-

learning infants would need to learn that the trochaic unit is the rhythmic unit of English, in order to use it to segment, the same might be true for the syllable in French, although it is also possible that French-learning infants could use the syllable to segment even without having learned that it is the rhythmic unit of French. This possibility relies on independent evidence suggesting that the syllable is a basic speech perception unit in the first months of life, and might thus be used as a default segmentation unit. For example, Bijeljac-Babic, Bertoncini, & Mehler (1993) found that newborns are sensitive to a change of number of syllables when presented with two-syllable versus three-syllable utterances, while they are not sensitive to a change of number of phonemes when presented with 4- versus 6-phoneme bisyllabic utterances.

How and when will the rhythmic unit be acquired? Because it is part of prosody, and because prosody is heard *in utero*, the acquisition of the rhythmic units will possibly rely on both pre- and post-natal experience.

In order to study the possible impact of prenatal exposure to speech on segmentation abilities, we replicated Experiment 4 with healthy very preterm (< 33 weeks) French-learning infants of the same chronological age (6 months after birth). Indeed, preterm infants differ in, at least, two important ways from full-term infants: neural maturation and prenatal exposure to speech (which is reduced in preterm infants). We predict that due to a lack of prenatal speech experience, preterm infants would be delayed in segmenting speech compared to full-term infants and thus fail to segment at 6 months, if the prosodic component (that is, the rhythmic unit) is the predominant cue for segmenting monosyllabic words at that age. However, if other cues play an equally important role, or if the syllable is the default segmentation unit, then preterm infants might also be able to use it to segment at 6 months in French.

3. Preterm infants present no delay in segmenting monosyllabic words

Developmental psycholinguistics generally focuses on how language perception develops through infancy and investigates the origins of language-related mechanisms. In a developmental framework, when an early ability is found, this finding can be used as a benchmark to study atypical development, and specify potential language delays. The two studies we conducted (Goyet et al., 2013; Nishibayashi et al., in press) reveal early segmentation abilities in 6- and 8-month-olds, hence providing a typical developmental trajectory in French infants. Given the growing body of evidence that preterm infants are delayed in several cognitive domains and the importance to prevent the corresponding disorders, we explored whether healthy French-learning very preterm infants (< 32 weeks, although one infant was born at 33) present early segmentation abilities as full-term infants at 6 months. In order to test such abilities, we replicated Experiment 4 which appeared to be the simplest segmentation condition used in the present thesis (single syllable segmentation).

Each year, more than one baby out of ten are born preterm (under 37 weeks of gestation). This results in 15 million preterm babies around the world (Kinney, Lawn, Howson, & Belizan, 2012). According to Niel (2011), the proportion of preterm births in France is increasing since 1992: there were 50 preterm births for 1000 in 1992, while there were 64 for 1000 in 2007. However, these statistics involve all preterm births (< 37 weeks of gestation). For very preterm birth (< 32 weeks of gestation), there are about 11 for 1000 (1.1%) per year since 2004 (Niel, 2011). Knowing that the total number of births in France in 2012 was around 820.000 (Institut National de la Statistique et des Études Économiques, 2013), the 1.1% represents over 9.000 infants born severely preterm (< 32 weeks) in France each year. Therefore, investigating the cognitive and linguistic development of such a population is of public health importance.

Many studies on preterm infants, toddlers and children reported delays and even impairments in numerous domains such as motor, cognitive and behavioral skills (e.g., Foulder-Hughes & Cooke, 2003; Cooke, 1994; Jongmans, Mercuri, Dubowitz, & Henderson, 1998). What about language perception, processing and production?

3.1. Introduction

Several studies have shown that infants born very preterm (under 32 weeks of gestation which is often linked to a very low birth weight, under 1500g) have higher risks of presenting deficits in their linguistic skills. The scientific literature on this issue is generally divided as follow: preschool- vs. school-aged linguistic skills and perceptual vs. production levels. At the production (written and oral) level, preterm children present less complex expressive language (Grunau, Kearney, & Whitfield, 1990), poorer vocabulary (Boyer et al., 2014), and delays in processing and reasoning (Crunelle, Le Normand, & Delfosse, 2003; Guarini et al., 2010). At the perceptual level, preterm toddlers and children present poorer language-related auditory memory and lower receptive understanding (Grunau, Kearney, & Whitfield, 1990; Briscoe, Gathercole & Marlow, 2001; Byrne, Ellsworth, Bowering, & Vincer, 1993). Although these studies show language impairments, it is rather unclear whether this is due to a lack of gestational maturation, hence neural maturation, or to a lack of speech experience *in utero*. Their developmental trajectory (when and how these impairments appear) remains mostly unknown. This is because, in the past decades, most of the studies concentrated their efforts on preschool- and school-aged children.

What about speech perception in the very first year of life in preterm infants? Considering that several early infants' perceptual abilities are good predictors of language proficiency in older children (Kooijman et al., 2009, 2013; Junge et al., 2012; Newman, Ratner, Jusczyk, Jusczyk, & Dow, 2006), including the segmentation abilities explored in the present study, it is interesting to investigate such abilities to determine whether very preterm infants (during their first year of life) have delays or/and impairments in early speech perception/processing without waiting to test them at the preschool or school ages in higher processing levels such as verbal production and comprehension.

At present, there are very few studies investigating preterm infants' early perception. One of these studies was carried out by Bosch (2011) on Spanish- and Catalan-learning monolinguals and Catalan-Spanish bilinguals. This study was conducted to explore whether preterm (corrected age) and full-term 8-month-old infants can segment speech. Using HPP, infants were familiarized with two passages, each containing a CVC or CCVC target word. They were then tested on lists of target words versus lists of control words (not heard during the familiarization) through 16 test trials (thus, each list was

heard 4 times). Results showed that full-term 8-month-olds oriented longer to the lists of control (novel) words compared to the lists of target (familiar) words, suggesting that they were able to segment the target words. In contrast, preterm infants did not show any preference, suggesting that they could not segment the target syllables (Figure 1.3.). Bosch (2011) thus provides evidence that preterm infants would be impaired in extracting a word form from the speech stream at an age when full-term infants are able to. However, Bosch suggested that this absence of segmentation effect (preference for control words over targets, namely a novelty preference) in preterm infants would be due to the complexity of the task and perhaps of the stimuli. Moreover, as mentioned in Nishibayashi et al. (in press), results in segmentation tasks using HPP can vary (e.g., familiarity preference → novelty preference) according to methodological parameters such as familiarization duration (30 s vs. 45 s) or presentation order (Passage-Word vs. Word-Passage). Note also that Bosch (2011) did not mention if there was a block effect in the test phase that could have shown a preference in the first two blocks (1st to 8th trial) but not in the last two blocks (9th to 16th trial). Hence, it is possible that preterm infants might segment, but that procedure-related factors prevented Bosch (2011) from observing such effects. Experiment 8 will explore this issue in French-learning healthy preterm infants.

Figure 1.3. Preterm and full-term results in the word form segmentation task used by Bosch (2011). Mean orientation times (ms) to target (familiar) and control (novel) words From Bosch (2011).

There are generally two main factors invoked to explain possible delays/impairment between healthy preterm and full-term infant's early abilities. One is related to a lack of neural maturation and the other is related to a lack of prenatal experience with speech.

Concerning neural maturation, Peña, Pittaluga and Mehler (2010), using ERPs, conducted a study to test Spanish-learning full-term and preterm infants on their ability to discriminate between two prosodically similar languages (Spanish vs. Italian) and two distant languages (Spanish vs. Japanese). Full-term infants were tested at two ages: 3 and 6 months after birth (FT3 and FT6). Preterm infants were also tested at two ages: 6 and 9 months after birth (PT6 and PT9). The difference in the tested ages between the two

groups is due to the fact that preterm infants, born nearly 3 months before the expected term age, were tested at the corrected age so that they were observed at the same maturational age as full-term infants. Thus, FT3 and PT6 on the one hand and FT6 and PT9 on the other hand had the same maturational age (see Figure 1.4.). Note also that FT3 had 3 months of speech exposure while FT6 and PT6 had 6 months and PT9 9 months.

Figure 1.4. Maturational age and duration of exposure to speech of the participants in Peña, Pittaluga, & Mehler (2010). Horizontal bars indicate the duration of intra- and extra-uterine life (green and yellow, respectively) for full-term 3- (FT3) and 6-month-olds (FT6) and preterm 6- (PT6) and 9-month-olds (PT9). From Peña, Pittaluga, & Mehler (2010).

Infants were presented with series of sentences in each of the three languages (Figure 1.5.). To explore whether preterm and full-term infants were able to discriminate these three types of languages and to investigate the effect of their neural maturation, Peña and collaborators compared the gamma-band responses elicited by each type of language in the PT6, PT9, FT3 and FT6. The authors found significantly greater gamma-band power for Spanish and Italian compared to Japanese, suggesting that all the infants considered Japanese as a different language. However, only FT6 and PT9 infants showed greater gamma-band power for Spanish than for Italian, suggesting they perceived Spanish and Italian as prosodically different, even if belonging to the same rhythmic class. In contrast, FT3 and PT6 infants did not differ in their neural response when comparing gamma-band power for Spanish and Italian, suggesting that contrary to FT6 and PT9, they did not discriminate the two prosodically similar languages. When comparing FT3 and FT6 (having different gamma-band responses), results show that only the older full-term infants were able to discriminate Spanish and Italian, giving credit to a neural maturation hypothesis to explain the developmental pattern of rhythmic discrimination in infants. Moreover, given that FT6 and PT6 display different neural response to Spanish and Italian (the former discriminating Spanish vs. Italian while the latter could not), the researchers suggested that this developmental lag in preterm infants would be due to their insufficient neural maturation.

Figure 1.5. Protocol used by Peña, Pittaluga, & Mehler (2010). Infants listened passively to a series of 18 utterances in Spanish, 18 in Japanese and 18 in Italian.

While Peña, Pittaluga, and Mehler (2010) explored native/nonnative rhythm discrimination in preterm infants at the sentence level, Herold, Höhle, Walch, Weber, and Obladen (2008) investigated their stress perception at the lexical level: exposure to prosodic properties of speech begins *in utero* and consequently, preterm infants are less exposed to these properties before birth than full-term infants. Herold et al. (2008) tested pre- and full-term German-learning infants aged 4 and 6 months. Using HPP, infants were presented with repetitions of the sequence /gaba/, following either the predominant trochaic pattern of German (e.g., /GAba/) or the opposite iambic pattern (e.g., /gaBA/) in a familiarization-test paradigm. Full-term 4- and 6-month-old infants discriminated the trochaic stimuli and the iambic ones. In contrast, preterm infants, at both ages, did not discriminate the two patterns. These results suggest that preterm infants have difficulties in processing prosody. Herold et al. (2008) suggested that the absence of discrimination in preterm infants at 4 and 6 months of age would be due to a lack in speech experience *in utero* and more precisely, a lack in prosodic experience.

Taken together, Peña et al. (2010) and Herold et al. (2008) studies show that preterm infants are impaired in prosodic perception compared to full-term infants. While one is arguing for a lack of neural maturation (Peña et al., 2010), the other suggests this difference would be due to a lack of speech exposure (Herold et al., 2008), although these two interpretations are non-exclusive. Importantly for our study, these two studies showed that prosodic perception/discrimination is impaired in preterm infants. This finding is interesting because the acquisition of rhythmic units (syllables for French; trochaic units for English) has been proposed to rely on prosodic acquisition. But, since syllables are also basic units in early speech perception, and might thus be default segmentation units, it is of importance to investigate whether syllabic segmentation is impaired in preterm infants.

So far, only Gonzalez-Gomez and Nazzi (2012a), tested preterm infants during the first year of life, on the acquisition of a non-prosodic property of their native language: phonotactic acquisition. More precisely, they tested whether preterm infants are delayed in the acquisition of the labial-coronal (LC) bias. The typological asymmetry between LC and CL (coronal-labial) words was found in several languages (MacNeilage et al., 1999; Vallée et al., 2001) in which more words start with a labial consonant (e.g., /p/, /f/, /m/, /b/) followed by a coronal consonant (e.g., /t/, /d/, /n/) than the other way round. This

LC bias is also found in infant's early production (MacNeilage et al., 1999). Thus LC structures like /bato/ [ship] are more frequent than CL structures like /tapi/ [carpet]. Consequently, the LC bias was found to translate into a perceptual advantage for LC words over CL words in adult word processing (for French: Sato et al., 2007). In French, the LC bias was found to appear between 6 and 10 months of age (Nazzi, Bertoncini, & Bijeljac-Babic, 2009b; Gonzalez-Gomez & Nazzi, 2012a). Following Gonzalez-Gomez and Nazzi (2012a), Gonzalez-Gomez and Nazzi (2012b), using HPP, studied the LC bias in full-term (at 7 and 10 months) and preterm (at 10 months – chronological age) infants. Infants were presented with lists of repeated CL and LC words. The presence of the LC bias would be marked by infants' preference (longer orientation time) for LC words compared to CL words. Results first showed that full-term 7-month-olds did not show any preference, suggesting an absence of the LC bias, while full-term 10-month-olds preferred LC words over CL ones, suggesting an LC bias. This finding confirmed the previous studies showing the emergence of the LC bias between 6 and 10 months in French-learning infants. Second, preterm 10-month-old infants, like full-term infants at the same age, presented a significant preference for LC sequences over CL ones. This study thus showed that preterm infants are not delayed in acquiring this phonotactic property of their native language. Furthermore, because preterm and full-term infants differed in their neural maturation but not in their amount of exposure to this phonotactic property, these results suggest that maturation *per se* is not crucial for phonotactic acquisition. Rather, it would be the experience with speech after birth that makes the LC bias emerges.

Following the above studies, we carried out a study on healthy French-learning preterm infants at 6 months, to observe whether preterm birth impacts word segmentation. We replicated Experiment 4 (monosyllabic word segmentation) with French-learning preterm 6-month-olds. If segmentation of monosyllabic words crucially depends on prenatal exposure to prosody, preterm 6-month-olds should be impaired in this segmentation ability. Otherwise, preterm 6-month-olds might present the same segmentation effect as found in full-term 6-month-olds (Experiment 4). Our preterm infants were all learning French; however some of them were monolinguals while the others were bilinguals (with varied second languages). Bilinguals' exposure to the second language never exceeded 50%.

3.2. Experiment 8: monosyllabic word segmentation in preterm 6-month-olds

3.2.1. Method

Participants

Fifteen healthy preterm 6-month-olds were included (7 females and 8 males; mean age: 6 months and 15 days; range: 6 months to 6 months and 29 days). Twelve additional infants were tested but not included due to not attending to the lights (10 - possibly due to non-sufficient motor skills to correctly turn their head during the experiment) or due to fussiness (2). 7 infants were from monolingual French-speaking families while 8 other infants were from bilingual families (with one of their language being French, and French constituting at least 50% of their overall language exposure). Other languages included Arabic (4 infants), Italian (1), Mandarin (1) and Swahili (2). All parents gave informed consent before participation and completed an information sheet. Preterm infants were recruited if, at birth, they had met three primary criteria: i) a gestational age under or equal to 33 weeks, ii) no indication of visual or hearing impairment, and iii) a normal neuropsychiatric examination. In the present experiment, the preterm infants' gestational ages ranged from 26 weeks to 33 weeks and 4 days ($M = 28$ weeks and 3 days).

Stimuli

The stimuli were the same as in the first experiment of Nishibayashi, Goyet, and Nazzi (in press) (Experiment 4 of present dissertation).

Four monosyllabic CV words (/di/, /po/, /te/, /gu/) were selected (see Table 1.1.). As in previous research on this topic, these target words were nouns with relatively low frequencies, as given in the adult database LEXIQUE 2 (New et al., 2004, given per 1 million occurrences, and calculated over a base of 31 million occurrences): /di/ = 4.86 (*dit* [a said]), /po/ = 32.3 (*pot* [pot]), /te/ = 44.19 (*thé* [tea]), /gu/ = 124.8 (*goût* [taste]). Moreover, they were not listed in the French CDI (Kern, 2003).

For each target word, an 8-sentence passage was created for the familiarization phase. The target words appeared either towards the beginning (4 times) or towards the end (4 times) of the sentences (Appendix 1.1). Mean number of syllables per sentence was 10. To prevent infants from relying on transitional probabilities to segment words, syllables preceding and following the target words were always different so that no specific syllabic sequences were repeated within the passages.

The sentences were recorded by a French-native female talker in a sound-attenuated booth. She was asked to produce the sentences with mild IDS (infant-directed

speech). The passages lasted 20 seconds each. For each syllable, the same talker also produced a list of 20 isolated occurrences for the test phase, which she produced with some variations to avoid infants' boredom and also to evaluate recognition of the targets in a condition with some acoustic variability. The four lists lasted 20 s each. Mean values of syllable duration, intensity and pitch for passages and lists are reported in Table 1.2.

Procedure, apparatus and design

Procedure was identical to Experiment 4 of present dissertation.

3.2.2. Results and discussion

Mean OTs were calculated for the lists containing the target versus the control words (see Figure 1.6.). A paired t-test showed a significant preference for target ($M = 9.24$ s, $SD = 2.83$) over control ($M = 7.91$ s, $SD = 2.55$) words ($t(14) = 3.03$, $p = .009$; Cohen's $d = .50$), with 12 of the 15 infants having longer OTs to the target words (one-tailed binomial test, $p = .02$).

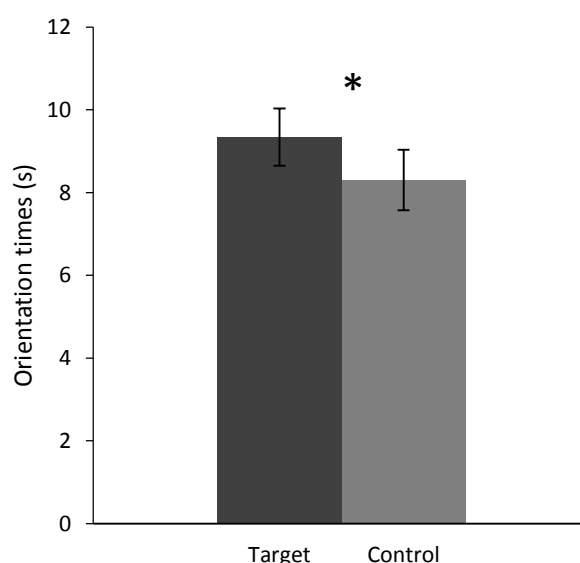


Figure 1.6. Mean orientation times (and SEs) to the target and control words in Experiment 8. * stands for $p < .05$.

However, our group was constituted of mono- and bilingual infants. Although the number of infants in each group is not large, the data were separated according to linguistic experience (Figure 1.7.), and we conducted a 2-way ANOVA with the main within-subject factor of familiarity (lists of target vs. lists of control words) and the

between-subject factor language (mono- vs. bilingual). The main effect of familiarity reached significance ($F(1,13) = 10.74$; $p = .006$, $\eta^2_p = .45$) while neither the factor of language ($F(1,13) = 1.76$; $p = .21$) nor the familiarity x language interaction $F(1,13) = 2.43$; $p = .14$) did. Although the interaction was not significant (possibly due to the limited number of infants), separated t-tests were nevertheless conducted on the two subgroups, which revealed a segmentation effect in the monolinguals ($t(6) = 3.56$, $p = .012$) (Mean Difference Score = 2.03; 6 out of 7 infants had positive difference scores) but not in the bilinguals ($t(7) = 1.19$, $p = .27$) (Mean Difference Score = .72; 6 out of 8 infants had positive difference scores).

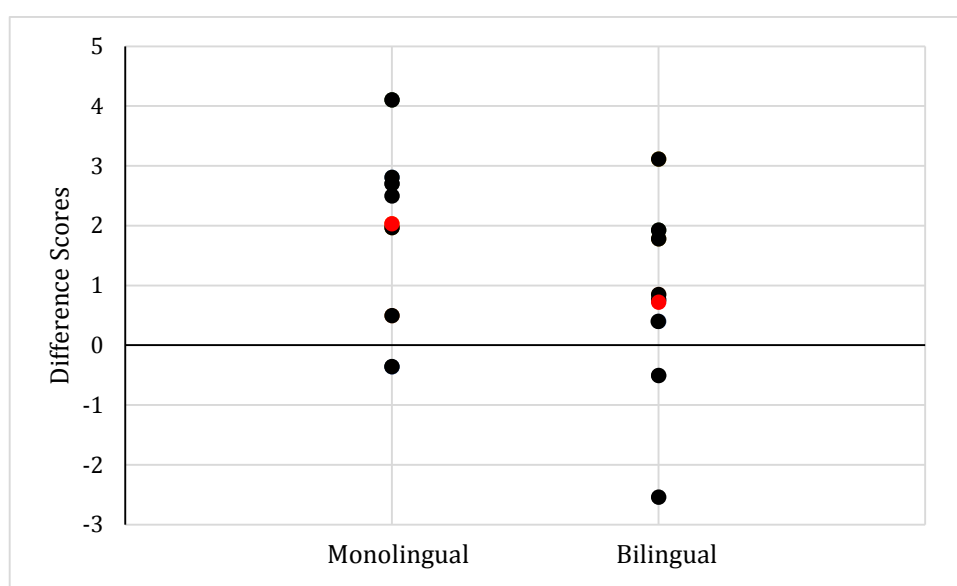


Figure 1.7. Difference Scores (DS) in Experiment 8 for each preterm monolingual (left panel) and bilingual (right panel) infant. A positive DS reflects a longer orientation time the target syllable. Each black dot represents one infant. Red dots are mean DS in monolingual and bilingual groups.

In this experiment, we wanted to determine whether French-learning preterm 6-month-olds are delayed or impaired in monosyllabic word segmentation. To investigate this issue, we replicated Nishibayashi et al. (in press) Experiment 1 (Experiment 4 of current dissertation) that had been conducted with full-term 6-month-olds. In several studies (Peña et al., 2010; Herold et al., 2008; Bosch, 2011), language acquisition in preterm infants has been found to be affected by less mature neural development and less experience with speech *in utero*. Our findings establish monosyllabic word segmentation at 6 months of age in preterm infants, under the same test conditions as in Experiment 4, with full-term 6-month-olds. This finding seems to be carried mostly by the monolingual

preterm infants. Additional infants will need to be included in this experiment to confirm the findings on larger groups, and determine whether this difference in linguistic experience would be confirmed or not. However, we can conclude for now that, like phonotactic acquisition (Gonzalez-Gomez & Nazzi, 2012a), monosyllabic word segmentation is not delayed in these French-learning preterm infants.

These findings differ from those of Bosch (2011), who found that Spanish/Catalan-learning preterm 8-month-olds were impaired in speech segmentation. Knowing that Spanish, Catalan and French are three syllable-based languages, the absence of a segmentation effect in Bosch (2011) is unlikely to be due to a difference in the use of syllabic units across these languages, but rather due to methodological reasons. While we tested recognition of the target syllables through 12 trials, Bosch (2011) presented 16 trials. Infants' sustained attention being limited, they usually pay less attention at the end of the test phase compared to the beginning. Thus, if too long, infants' attention decreasing, the segmentation effect would only emerge in the first trials while it would disappear in the last trials. A way to explore this possibility would be either to make comparisons between the first and the last trials or to make a shorter test phase as done in current Experiment 8. Another methodological reason could be related to the duration of familiarization. Bosch (2011) familiarized infants during 1 minute and a half (45 seconds to each passage) while we familiarized infants during 1 minute (30 seconds to each passage). Importantly, according to Hunter and Ames (1988), observing a familiarity, novelty or no preference is partly dependent on familiarization duration. While a familiarization duration of 30 s (as used in our Experiment 8) appears to induce a familiarity preference, lengthening familiarization duration (as done by Bosch, 2011) might induce a partial switch from a familiarity to a novelty preference, resulting in equal orientation times to target and control words.

In the present experiment, preterm infants were tested on a simple monosyllabic word segmentation (simpler than embedded syllables or bisyllabic words segmentation as shown in Nishibayashi et al., in press), which might be segmented based on the rhythmic unit cue, but also based on other non-prosodic cues (that cannot be specified from the results of this sole experimental condition). Given that, preterm infants were found to have a delay in prosodic perception/acquisition (Herold et al; Pena et al) our result, showing that 6-month-old preterm infants do segment monosyllabic words like full-term infants has implications for the mechanisms underlying this segmentation. The

rhythmic bootstrapping hypothesis for segmentation being a prosodic-based hypothesis, preterm birth should impact early rhythmic segmentation, so why did we find no delay? A first possibility is that, during the first year of life, infants use the rhythmic units of their native language combined with other segmentation cues such as coarticulation, phonotactic cues or TPs (as demonstrated by Goyet et al., 2013). From this perspective, preterm birth could hinder the acquisition of rhythmic units but infants would still be able to use other cues that are acquired through postnatal speech exposure (which is the same between preterm and full-term infants, at the same chronological age). Future experiments will be needed to determine preterm infants' use of these other segmentation cues. Second, the syllable, before acquiring its rhythmic unit status in syllable-based languages, could be a more basic processing unit as suggested by Bijeljac-Babic et al. (1993), and present cross-linguistically. French being a syllable-based language, the rhythmic and the basic status of the syllable are confounded, and French-learning infants would be able to use syllables to segment before acquiring their native language-specific status as rhythmic units. To test this possibility, a replication of Experiment 8 is needed in a stress-based language such as English.

It is also important to underline that the preterm infants we included in this experiment are the ones who could turn their heads correctly during the HPP. What we do not know is whether the preterm infants we excluded are able to segment speech. One possible way to explore this question taking into account their motor skill problems would be to conduct the same study in a slightly modified version of HPP (also used at 4 months by Herold et al., 2008), where the red lights would be placed on the central panel alongside the green light (see Figure 1.8.). This would limit the required headturns, and might thus facilitate the observation of sound processing in this population with motor impairment.

Figure 1.8. Modified version of the HPP set-up. Usual HPP set-up (left panel, image from Gervain & Werker, 2013) and modified version (right panel) for preterm infants testing.

Lastly, the studies conducted on Dutch-learning (Kooijman et al., 2013) and French-learning (Goyet et al., 2010) full-term infants establishing an electrophysiological signature of word form segmentation, should be replicated in preterm infants. Importantly, Kooijman et al. (2013) showed that this electrophysiological signature

changes during development from a less mature positivity to a more mature negativity. Comparing the ERP signature of segmentation in pre- and full-term infants would allow us to specify whether the similar behavior we observed in both full- (Experiment 4) and preterm (Experiment 8) 6-month-old infants is based on the same neural processes at the same level of maturational development.

4. General Discussion

This first experimental chapter investigated early segmentation abilities in French-learning infants, exploring Nazzi et al. (2006) early rhythmic bootstrapping hypothesis. In this hypothesis, Nazzi et al. (2006) proposed that very early on, infants would acquire and use the rhythmic unit of their native language to extract their first word forms from speech streams. According to this hypothesis, the rhythmic units will differ from one language to another. English being a stress-based language with a predominant trochaic pattern at the lexical level, English-learning infants would use trochaic units to segment speech. In contrast, French being a syllable-based language, French-learning infants would use syllabic units to segment speech.

Although many cues have been proposed to help infants segmenting speech, two segmentation cues are generally more investigated because they are considered the most important: transitional probabilities (Saffran et al., 1996b) and rhythmic units (Nazzi et al., 2006). The two papers described in this experimental chapter investigated the use of syllabic units for segmentation in French-learning infants. While both papers showed that syllabic units are used in segmenting speech in French during the first year of life (at 8 and 6 months respectively), the first paper showed that TPs are also involved (when TPs point to bisyllabic units, syllabic segmentation is not observed any more) and the second showed that coarticulation is also likely to impact segmentation.

To observe when segmentation abilities emerge during the first year of life and how TPs and rhythmic units are used during this emergence, we conducted a series of experiments, using HPP. The general procedure used in this series was always the same: after familiarization with two passages each containing a target word, infants were tested on two lists corresponding to the target words versus two lists corresponding to control words not heard during familiarization. Evidence of segmentation ability is revealed by infants' preference for one of the two types of lists (target vs. control).

In Experiments 1 – 3 (Goyet et al., 2013) we manipulated the weight of TPs at the sentence level, the goal being to find evidence of syllabic segmentation at 8 months. In Experiment 1, we reevaluated syllabic segmentation in a context in which TPs were moderately reduced. This reduction was done by alternating target syllables in different word positions (two words containing the same target syllable in initial position and two words in final position) within passages. Results showed that French-learning 8-month-

olds were not able to segment the target syllable. One possibility to explain this null segmentation effect is that infants were segmenting bisyllabic words rather than the target syllable alone. Thus, in Experiment 2, we tested this possibility by presenting the same passages during familiarization, and testing infants on the bisyllabic words containing the target syllables and heard during familiarization. In this same context of moderate TP reduction, infants were not able to segment those bisyllabic words, hence, suggesting that the absence of segmentation effect in Experiment 1 was not due to the fact that infants were segmenting bisyllabic words. Therefore, in Experiment 3, we lowered the TPs even more by presenting in each passage, 8 different bisyllabic words that contained the same target syllable (instead of two different words sharing the same syllable as done in Experiment 1). Infants were then tested on their ability to segment the target syllables, and evidence of an early syllabic segmentation was found. Taken together, these experiments provide evidence of the use of TPs and syllabic units in early segmentation in French. While infants could not extract the target syllable in the moderate TP reduction (Experiment 1) they were able to do so when the TPs were even lower (Experiment 3). These experiments thus establish syllabic segmentation by 8 months, while giving new insights on how TPs and rhythmic units are used in interaction for segmenting speech during the first year of life.

In Experiments 4 – 7 (Nishibayashi et al., in press), we manipulated the context in which syllables were realized at the sentence level to see whether French-learning infants have acquired and make use of their native rhythmic unit, namely the syllable. The original study of Jusczyk et al. (1999) supports the rhythmic bootstrapping hypothesis (Nazzi et al., 2006) for English. In that study, English-learning 7.5-month-olds were found to segment trochaic units from speech but not iambic units, while 10.5-month-olds could do both. These results might reflect the developmental pattern English-learning infants follow: they begin to segment speech using the predominant trochaic pattern of their language (which is the rhythmic unit of English) and, through a few more months of experience to speech, they become able to segment the less frequent iambic pattern by probably using other segmentation cues. If the rhythmic segmentation hypothesis (Nazzi et al., 2006) is correct, a similar pattern should be observed in French-learning infants, showing that infants begin segmentation with the rhythmic unit of their native language (the syllable) and later become able to segment other types of words (bisyllabic words).

To evaluate this prediction, Experiment 4 tested whether French-learning 6- and 8-month-olds are able to segment monosyllabic words. Infants succeeded at both ages. What about segmenting syllables that are part of bisyllabic words? To answer this question, Experiments 5 and 6 tested 6-month-olds' ability to segment syllables that are embedded in bisyllabic words, replicating Experiment 3 (where segmentation of embedded syllables was possible at 8 months when TPs were at their lowest, each target syllable appearing in 8 different bisyllabic words during familiarization). While 6-month-old infants failed to extract target syllables when familiarized during 1 minute (30 seconds to each passage), they demonstrated clear segmentation effects when familiarized during 1 minute and a half (45 seconds to each passage). The only difference between Experiments 5 and 6 being the familiarization duration, we can conclude that segmenting embedded syllables is more demanding than segmenting monosyllabic words (Experiment 4). Moreover, the difference between Experiment 4 on the one hand and Experiments 5 and 6 on the other hand, being the context in which the syllables appear (as monosyllabic words or embedded in bisyllabic words), this difference in findings suggests that infants might be sensitive to coarticulation cues. Finally, Experiment 7 tested whether 6-month-old infants are able to segment whole bisyllabic words following the longer familiarization used in Experiment 6. Experiment 7 failed to show a bisyllabic segmentation effect. Taken together, Experiments 4-7 provide evidence of a privileged use of syllabic units to segment speech at 6 months. Indeed, French-learning infants appear to first segment speech in syllabic units (around 6 months of age), before they start segmenting bisyllabic words as whole units two months later. This developmental pattern supports the early rhythmic bootstrapping hypothesis (Nazzi et al., 2006).

According to the rhythmic segmentation hypothesis (Nazzi et al., 2006), the rhythmic unit of the native language is acquired very early on, due to exposure to the prosody (rhythm) of the native language. Knowing that infants are born with about three months of prenatal exposure to the prosody of their native language, testing preterm infants can provide further insights on how early the rhythmic units are acquired, as preterm birth deprives infants of prenatal exposure to speech rhythm. Therefore, in Experiment 8, we replicated Experiment 4 with healthy preterm French-learning 6-month-olds (chronological age) born before 33 weeks of gestational age (thus losing about three months of prenatal prosodic experience). Results show that preterm infants, as the full-term infants of the same age (Experiment 4), are able to segment monosyllabic

words. This establishes that there is no developmental lag between preterm and full-term infants in segmenting monosyllabic words. This contrasts with the hypothesis that infants use the rhythmic units of their native language to segment speech and with previous studies showing a developmental lag in prosodic processing and acquisition in preterm infants (Peña et al., 2010; Herold et al., 2008). A first explanation for this lack of delay is that, even if the acquisition of the rhythmic unit is impaired in preterm infants, they can still segment monosyllabic words by using other segmentation cues (such as TPs and coarticulation) that are acquired through speech experience after birth. A second possibility is that the syllable is a basic perceptual unit, as shown by Bijeljac-Babic et al., (1993) in newborns, and is used as a default segmentation unit by preterm infants before they learn it is the rhythmic unit of their native language.

To conclude, Chapter 1 of the present thesis provided for the first time evidence of syllabic segmentation in French-learning infants as early as 6 months. This series of experiments thus supports the rhythmic bootstrapping hypothesis (Nazzi et al., 2006). Moreover, the procedure used and the results obtained at 6 and 8 months of age provide an excellent tool to study the development of other language-related mechanisms. Accordingly, in the next chapter, we describe a series of experiments using the same procedure in order to investigate how infants make use of consonants and vowels to recognize segmented words forms at 6 and 8 months of age.

**EXPERIMENTAL CHAPTER 2:
CONSONANT/VOWEL ASYMMETRY
IN EARLY LEXICAL PROCESSING**

Abstract

To learn and recognize words, Nespor et al. (2003), in their *division of labor* hypothesis, suggested that consonants would be more important than vowels (the latter being more involved at the prosodic and syntactic levels). Indeed, many adult and toddler studies demonstrated that consonants are given more weight than vowels in identifying words: this is called the consonant bias. The aims of the studies presented in the present chapter were 1) to determine when the consonant bias appears in early development and 2) to determine its origin. The present chapter is based on a paper in preparation (Nishibayashi & Nazzi, in prep.).

Using the Headturn Preference Procedure (HPP), we conducted a series of segmentation experiments, familiarizing infants with passages containing two monosyllabic target words and testing them in different conditions. In a pilot experiment (Experiment 9), French-learning 8-month-olds were tested on lists of isolated target words versus lists of target words mispronounced either on the vowel or on the consonant. This pilot experiment failed to show any significant effect. This absence of results might have been due to the phonetic similarity of the targets and mispronunciations at test. In Experiment 10, we tested infants on lists of control words (hence presenting no phonetic similarity with target words) versus lists of target words mispronounced either on the vowel or on the consonant. Experiment 10 showed a significant segmentation effect in the vowel mispronunciation condition and a null effect in the consonant mispronunciation condition, suggesting that at 8 months, infants considered the vowel mispronunciation (but not the consonant mispronunciation) as similar to the target word, hence showing a consonant bias in recognizing segmented word forms. To further investigate the relative weight given to consonants and vowels, Experiment 11 was conducted: infants were tested on lists of vowel mispronunciations versus consonant mispronunciations (namely a conflict task). Experiment 11 showed a significant segmentation effect in favor of the vowel mispronunciation suggesting, as Experiment 10, a consonant bias. Finally in Experiment 12, we tested 6-month-olds to see whether the consonant bias could be observed at an earlier age. Experiment 12 revealed the opposite segmentation pattern: 6-month-olds oriented longer to the consonant mispronunciations, suggesting a vowel bias. Taken together these results show that 1) the consonant bias seems to appear between 6 and 8

months of age and 2) the origin of the consonant bias would be prelexical rather than lexical and would appear through phonological experience to speech.

1. Is the C-bias present at 8 months in French-learning infants?

Consonants and vowels are two phonological categories structuring speech in all languages (Ladefoged, 2001) and several differences between these two categories can be observed at different levels. First, consonants are cross-linguistically more numerous than vowels: the majority of languages have more than 20 consonants while five vowel systems are the most common. Systems having more vowels than consonants, like Swedish or Danish are very rare (Maddieson, 1984; Ladefoged & Maddieson, 1996). Second, these two categories differ at the acoustic level: vowels tend to be longer and have more energy than consonants (Repp, 1984; Ladefoged, 2001), making them more easily perceivable in utero (Granier-Deferre, Ribeiro, Jacquet, & Basserau, 2011), leading to greater experience with vowels compared to consonants at birth. However, consonant contrasts appear to be overall more discriminable than vowel contrasts when normalized for duration and intensity (Bouchon et al., in press). Third, at the perceptual level, consonants are processed more categorically (Fry, Abramson, Eimas, & Liberman, 1962) and faster than vowels (Vergara-Martinez, Perea, Marin, & Carreiras, 2011) and seem to activate different brain areas (Carreiras & Price, 2008; Caramazza, Chialant, Capasso, & Miceli, 2000). Fourth, while they initially discriminate native and nonnative phoneme contrasts (for a review, see Kuhl, 2004), infants start acquiring their native vowel inventory around 6 months of age (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Polka & Werker, 1994), while it is generally considered that infants start acquiring their native consonant inventory (Werker & Lalonde, 1988; Werker & Tees, 1984) around 10-12 months of age. Lexical acquisition starts at about the same age, although several studies found that proper names such as *Mommy* or *Daddy* (Tincoff & Jusczyk, 1999) and some common names such as *Apple* (Bergelson & Swingley, 2012) are already recognized around 6 months of age.

Since the earliest evidence of word comprehension is found around 6 months (Bergelson & Swingley, 2012; Tincoff & Jusczyk, 1999, 2012), many studies have investigated the link between early phonological and lexical acquisition by exploring the way infants recruit their early perceptual capacities, especially their ability to perceive

and process consonant and vowel contrasts, in lexical processing. The differences between consonants and vowels have led Nespor et al. (2003) to propose a functional ‘division of labor’ that could help infants learn their native language. Of importance for the present study, this hypothesis proposed a consonant bias (C-bias) at the lexical level: consonants would be more involved in learning and identifying words than vowels (which are proposed to be more involved at the prosodic and syntactic levels). The present study will investigate the role of the C-bias in recognizing segmented word forms and further explore its developmental origin.

1.1. Introduction

Many studies on adults have explored the consonant/vowel functional asymmetry, and found evidence of a greater reliance on consonants over vowels at the lexical level, hence a lexically-related C-bias, in tasks tapping written and oral lexical access (Cutler et al., 2000; New, Araùjo, & Nazzi, 2008; New & Nazzi, 2014; Acha & Perea, 2010; Delle Luche, Poltrock, Goslin, New, Floccia, & Nazzi, 2014; van Ooijen, 1996), word segmentation (Bonatti, Pena, Nespor, & Mehler, 2005; Toro, Nespor, Mehler, & Bonatti, 2008) and word learning (Havy, Serres, & Nazzi, 2014; Creel, Aslin, & Tanenhaus, 2006). Some of these studies, carried out by van Ooijen (1996) and Cutler et al. (2000) with English, Spanish and Dutch adults, showed a C-bias in lexical tasks: subjects were presented with non-words and each could be changed into a real word by substitution of a single consonantal or vocalic phoneme. The subjects were asked to press a response key as soon as they had thought of a real word substitution. Results showed that listeners in all 3 languages found it easier to create a real word by altering a vowel than by altering a consonant. Moreover they were faster and more accurate when they were constrained to do a vowel substitution than a consonant substitution. These results established that adults prefer to change a vowel rather than a consonant to find a word, hence found that preserved consonant information was more important than preserved vowel information. More recently, Delle Luche, Poltrock, Goslin, New, Floccia, and Nazzi (2014) tested French and English adults on a lexical decision task in different priming conditions: consonant-related, vowel-related and unrelated conditions. In the consonant-related condition, the prime and the target words shared the consonants while the vowels were minimally changed (e.g., /keʁø/ - /kaʁø/). In the vowel-related condition, the prime and the target shared

the vowels while the consonants were minimally changed (e.g., /gaʒo/ - /kaʒo/). In the unrelated condition, the prime and the target words shared no phoneme (e.g., /geʒø/ - /kaʒo/). English and French subjects were then evaluated on their priming effect (facilitation effect showed by faster reaction times) in the different conditions. Results showed that, overall, both English- and French-listeners had a larger priming effect in the consonant-related condition than in the vowel-related condition. These findings demonstrate that consonants have a lexical advantage over vowels in accessing lexical representations, hence a C-bias in processing words. Moreover, since this consonant advantage was found in two different languages (French and English), the C-bias might be present cross-linguistically (although other languages should be tested).

In this context, many studies have explored the C-bias in toddlers during the second year of life, in order to determine its origin and specify potential changes in how consonants and vowels are processed during development. One of the first studies was conducted in French by Nazzi (2005) and used an interactive learning task, namely the name based categorization (NBC) task. In this study, French-learning 20-month-olds were presented with triads of new objects, two of the objects receiving the same name and the third receiving a name differing by a one-feature phonetic change (e.g., /pize/ vs. /tize/ in the consonant condition, and /pize/ vs. /pyze/ in the vowel condition). Infants' ability to learn the labels was evaluated by their recognition of the object-label links. Infants were considered to have learnt a new word when succeeding in pairing the two novel objects labelled with the same name. Performance was better with consonant- than vowel-contrasted pairs, establishing a C-bias in word learning at 20 months. Similar results were found in different word learning tasks in French-learning 16-, 20- and 30-month-olds (Havy & Nazzi, 2009; Nazzi & Bertoncini, 2009; Nazzi & New, 2007), 3-, 4- and 5-year-old children and adults (Havy, Bertoncini, & Nazzi, 2011; Havy, Serres & Nazzi, 2014). Moreover, a C-bias was also observed in familiar word recognition by French-learning 14-month-olds (Zesiger & Jöhr, 2011), infants neglecting vowel mispronunciations but not consonant mispronunciations. These findings thus establish a relatively early C-bias in lexical processing in French, calling for further studies to explore whether this bias is universal or language-general, and to specify its origin.

Three hypotheses regarding the origin of the C-bias have been proposed. The "initial bias" hypothesis (Nespor et al., 2003; Bonatti, Pena, Nespor, & Mehler, 2005; Pons & Toro, 2010) states that the C-bias is present from birth, infants processing consonants

and vowels as distinct phonetic categories from the very beginning. This hypothesis thus predicts no developmental or cross-linguistic differences.

In contrast, two hypotheses proposed that the C-bias is learned. Keidel et al. (2007) hypothesized that the C-bias could reflect experience with distributional information at the level of the lexicon, from which adults could have learned that consonants are more informative than vowels in recognizing words (“lexical” hypothesis). Indeed, in their analysis of the 4943 CVCVCV words in the French corpus Lexique 3 (New, Pallier, Ferrand, & Matos, 2001) conducted to determine the mutual informativeness of consonants and vowels, they found that consonants are more informative than vowels in this language, hence that the French adults showing a C-bias in Bonatti et al. (2005) could have learned, through a lifetime of experience indicating that consonants are more informative than vowels at the lexical level, to attend to consonants in lexical processes. Given the findings of a C-bias in French 14-to-16-month-olds (Havy & Nazzi, 2009; Zesiger & Jöhr, 2011), this acquisition would have happened in the early stages of lexical acquisition, although probably after 12 months when infants have learned a large enough lexicon. Note that contrary to the initial bias hypothesis, this lexical hypothesis predicts that the C-bias might change in development for a given language (with lexical acquisition) and might be modulated cross-linguistically depending on the relative mutual informativeness of consonants and vowels at the lexical level in each given language.

More recently, an “acoustic/phonetic” hypothesis (Floccia, Nazzi, Delle Luche, Poltrock, & Goslin, 2014; Bouchon, Floccia, Fux, Adda-Decker, & Nazzi, in press) has been proposed, suggesting that the C-bias also emerges during development but due to infants’ early experience with the acoustic-phonetic properties of consonants and vowels in their native language, rather than due to learning at the lexical level. Some early differences in processing consonants and vowels (e.g., the former being processed more categorically than the latter) would lead infants to discover their functional asymmetry, and give consonants more weight in word processing. Furthermore, natural languages differing by many consonantal and vocalic aspects (C/V ratios, vocal realization, reduction, harmony, etc.), this hypothesis proposes cross-linguistic differences in the emergence of the C-bias, leaving open the possibility of its absence, or of a reversed vowel bias if appropriate. If this hypothesis is correct, then we should observe differences in how the C-bias influences speech across languages and also we should be able to observe it during the first year of life, when infants start acquiring their vocalic and consonantal inventories and do not

have a sizeable lexicon yet. Therefore the only way to test these three hypotheses is cross-linguistic developmental investigations.

While one hypothesis (Nespor et al., 2003) suggests no cross-linguistic differences in the C-bias, the two others (Keidel et al., 2007 for the lexical hypothesis; Floccia et al. 2014 and Bouchon et al., in press for the acoustic/phonetic hypothesis) predict cross-linguistic differences in the C-bias due to the differences observed at the acoustic/phonetic and lexical levels across languages. Accordingly, some studies have been conducted on English-learning toddlers, overall failing to find evidence of an early C-bias. While one experiment suggested that familiar word recognition was more impaired by consonant than vowel mispronunciations at 15 months (Mani & Plunkett, 2007), this finding could not be replicated in other experiments or other ages (Mani & Plunkett, 2007, 2010). For new word learning in English, the C-bias was found at 30 months (Nazzi et al., 2009a) but not between 16 and 24 months (Floccia et al., 2014). Recently, Højen and Nazzi (in revision) explored the C-bias in Danish-learning 20-month-olds using the same task as Havy and Nazzi (2009). Danish-learning toddlers were found to succeed only with labels differing by one or two vocalic features while they failed to do so with one or two consonantal feature contrasts. This finding establishes a vowel bias (V-bias) contrary to the C-bias found for French-learning infants at the same age (Nazzi, 2005). Højen and Nazzi (in revision) thus provide evidence that the C-bias is not present cross-linguistically and that the early biases (C- or V-bias) observed would be shaped by the language spoken in the infants' environment. For Danish the V-bias could come from some lexical or phonological properties as suggested by Højen and Nazzi (in revision).

Taken together, these results do not provide evidence of a language-general C-bias during the second year of life. But does it mean that the C-bias is not present from birth (hence, going against the initial bias hypothesis proposed by Nespor et al., 2003) and rather is learned during development? Or is it possible that the C-bias is present in all newborns, but then is maintained (in French), disappears (in English) or reverses (in Danish) around 16-20 months of age? To address this issue, studies on the C-bias during the first year of life are needed to determine its development.

To explore these possibilities, two research strategies have been used. The first one is a cross-linguistic approach, which aims at testing the prediction from the initial bias hypothesis that the C-bias is language-general, hence not modulated cross-linguistically (Mani & Plunkett, 2007, 2010; Nazzi et al., 2009a; Floccia et al., 2014, for English; Højen &

Nazzi, in revision, for Danish). Results revealed cross-linguistic differences, not predicted by the initial bias hypothesis. However, these studies mainly tested toddlers during their second year of life when they already have acquired a sizeable lexicon and have already started acquiring the vocalic and consonantal inventories of their native language. These acquisitions could have modified the proposed initial C-bias in language-specific ways. Hence, in order to further explore the origins of the C-bias in lexical processing, it is crucial to test young infants, during the first year of life, in order to establish how they use consonantal and vocalic information in lexically-related processing before they have a sizeable lexicon.

Therefore, several studies focused on the first year of life and start to provide evidence of a C-bias in infancy. Hochmann, Benavides-Varela, Nespor, and Mehler (2011) explored the possibility of a C-bias at 12 months in Italian-learning infants. In their study, infants had to learn new word form-object pairings. Infants were seated in front of a screen: while a first word was labeled, an object appeared on one side of the screen, while when the second word was labeled, the second object appeared on the other side. All the stimuli were CVCV non-words (e.g., /dede/ and /kuku/). After familiarization with 2 word-object pairings, infants heard two new words: one was made of the consonants of the first label and the vowels of the second (e.g., /dudu/) and the other was made of the consonants of the second label and the vowels of the first (/keke/). At test, audio presentations were not followed by object appearances so that infants had to anticipate the side on which the object would appear. The rationale of this conflict task is that if infants give more weight to consonants as predicted by the C-bias, they should attend to the side predicted by consonants rather than the side predicted by vowels. Results showed that infants indeed anticipated that the objects appear on the side predicted by consonants and not on the side predicted by vowels. This finding thus provides evidence of a C-bias at 12 months in Italian-learning infants.

Following this finding, Poltrock and Nazzi (in revision) explored the emergence of the C-bias even earlier, in French-learning 11-month-olds, using a familiar word recognition task. Using HPP, the authors first verified that, when presented with both familiar and unknown words (non-words), infants had a preference for familiar words. Then in a second experiment, infants were presented with lists of mispronounced familiar words in which the mispronunciation occurred either on a consonant (C-MP e.g., /gato/ [cake] → /gapo/) or on a vowel (V-MP e.g., /gato/ → /gatø/). French-learning 11-month-

olds oriented preferentially to the V-MPs compared to the C-MPs. Given that the baseline experiment established a preference for familiar words, the preference for V-MPs over C-MPs indicates that word recognition is more impacted by consonant alterations than by vowel alterations. This pattern of results reveals that infants rely more on consonants than on vowels, hence shows a C-bias in a familiar word recognition task.

A different picture emerges from Bouchon et al. (in press) testing French-learning infants at 5 months on the recognition of their own names. In order to be sure any significant effect would not be due to pure acoustic preference to the names, Bouchon et al. (in press) first conducted two control experiments where infants were presented with proper names other than their own, either correctly or mispronounced. Thus, in the control consonant condition, infants that had a name starting with a consonant would hear another infant's name beginning by a consonant and its consonantal mispronunciation (e.g., an infant named *Martin* heard *Victor* vs. *Zictor*). The same rationale was used for infants in the control vowel condition (e.g., an infant named *Adrien* heard *Esther* vs. *Isther*). In both consonant and vowel control experiments, infants listened equally to the correctly and mispronounced names, hence suggesting that none of the names elicited pure acoustic preference. Two main experiments were then carried out in which infants were presented with repetitions of their names correctly pronounced versus mispronounced, the mispronunciation being either on a consonantal phonetic feature (for consonant-initial names; e.g., *Victor* vs. *Zictor*) or on a vocalic phonetic feature (for vowel-initial names; e.g., *Esther* vs. *Isther*). The rationale was that if 5-month-olds have a C-bias in recognizing their names, they would display a preference for the correctly pronounced compared to the mispronounced name in the consonant condition, while they would have no preference in the vowel condition. Surprisingly, French-learning 5-month-olds had no preference in the consonant condition, while they preferred their correctly pronounced names in the vowel condition. Therefore, at 5 months, infants showed a vowel bias (V-bias) in this familiar word recognition task. This result does not support the initial bias hypothesis proposed by Nespor et al. (2003) and on the contrary, it suggests that the C-bias emerges during the first year of life.

The most recent studies carried out in French (Bouchon et al., in press; Poltrock & Nazzi, in revision) suggest that the C-bias emerges between 5 (V-bias) and 11 months (C-bias). Thus, taken together, they support the acoustic/phonetic hypothesis postulating that the C-bias would emerge from early experience with the acoustic/phonetic

characteristics of a given native language. However, these previous studies used different types of stimuli: infants' own names at 5 months and familiar words at 11 months. Therefore the switch of bias (V-bias to C-bias), observed between 5 and 11 months of age, could be due to the nature of the stimuli used. Indeed, while familiar words refer to multiple instances of a category, proper names refer to an individual object, hence giving names a particular status (Hall, 2009). Moreover, infants own names might be produced with more prosodic variation. Given that prosodic information is more carried by vowels, the evidence of more weighted vowels in Bouchon et al. (in press) could be due to a particular saliency of vowels in infants' own names. Therefore, to further explore this issue of the emergence of the C-bias, experiments between 5 and 11 months with a unique word type and procedure should be conducted. Hence, we carried out Experiments 9-12 in 6- and 8-month-old infants with a unique type of word.

Recently, several segmentation studies using the Headturn Preference Procedure (HPP), showed that both 6- and 8-month-old French-learning infants are able to segment monosyllabic CV words and CV syllables embedded in bisyllabic words (Goyet et al., 2013; Nishibayashi et al., in press) from the speech stream. In the experiments on monosyllabic words, infants were familiarized with two passages, each containing a target CV word. They were then tested with two lists made up of repetitions of the isolated target words versus two lists made up of repetitions of control words (not heard during the familiarization phase). At 6 and 8 months, infants oriented longer to the target words compared to the control ones, a familiarity preference demonstrating early syllabic segmentation.

This evidence of segmentation abilities in French-learning 6- and 8-month-olds provides an opportunity to explore the developmental trajectory of the C-bias in French by testing whether their recognition of the segmented targets is reduced or impaired if the targets presented at test are mispronounced on either the consonant or the vowel, and whether such effects differ with age. Accordingly, in a pilot experiment (Experiment 9), as in Nishibayashi et al. (in press), we familiarized 8-month-old infants with two passages, each containing a monosyllabic CV target word. Then we tested infants in two conditions. In the vowel condition, infants were presented with correctly pronounced targets (e.g., /ti/) versus vowel mispronunciations (V-MP) of the targets (e.g., /te/). In the consonant condition, infants were presented with correctly pronounced targets (e.g., /py/) versus consonant mispronunciations (C-MP) of the targets (e.g., /by/). If infants

have a C-bias, they should neglect the V-MPs while they should be affected by the C-MPs. Therefore, infants should consider the V-MPs as similar to the target words, and hence orient equally to the targets and the V-MPs in the vowel condition. In contrast, in the consonant condition, infants should consider the C-MPs as different from the target words, and hence orient longer to the targets compared to C-MPs. French-learning infants were thus tested at 8 months, an age at which no consonant/vowel comparative data still exist.

1.2. Experiment 9: target words vs. mispronunciations at 8 months

1.2.1. Method

Participants

A total of 40 healthy full-term infants were included (21 females and 19 males). They were 8 months of age (mean age: 8 months and 14 days; range: 8 months to 8 months and 28 days). Five additional infants were tested but not included due to fussiness (2) or crying (3). All the infants were from monolingual French-speaking families. All parents gave informed consent before participation and completed an information sheet.

Stimuli

Eight pairs of monosyllabic target CV words were selected. Words in a pair differed by a one phonetic feature change. In order to get results generalizing beyond a single phonetic change, we selected 4 consonantal contrasts: 2 on voicing (/py/ - /by/, /zu/ - /fu/) and 2 on place (/ta/ - /ka/, /di/ - /gi/); and 4 vocalic contrast: 1 on, roundness (/fã/ - /fĩ/), 1 on height (/ti/ - /te/) and 2 on place (/py/ - /pu/, /gø/ - /go/) (see Table 2.1.). These target words were nouns with relatively low frequencies, as given in the adult database LEXIQUE 3.5 (New et al., 2004, given per 1 million occurrences, and calculated over a base of 31 million occurrences) – /py/ = 0.20 (*pus* [pus]), /by/ = 51.89 (*but* [purpose]), /zu/ = 2.36 (*joug* [yoke]), /fu/ = 13.99 (*chou* [cabbage]), /ta/ = 83.78 (*tas* [pile]), /ka/ = 217.36 (*cas* [case]), /di/ = 4.86 (*dit* [a said]), /gi/ = 2.50 (*gui* [mistletoe]), /fã/ = 0.54 (*faon* [fawn]), /fĩ/ = 376.15 (*fond* [background]), /ti/ = 0.34 (*tee* [tee]), /te/ = 44.19 (*thé* [tea]), /py/ = 0.20 (*pus* [pus]), /pu/ = 1.42 (*pou* [louse]), /gø/ = 3.65 (*gueux* [beggar]), /go/ = 2.70 (*go* [go game]).

Table 2.1. Consonant and vowel contrasts manipulated in Experiments 9 & 10.

Vowel condition	Roundness	/fã/	/f5/
	Height	/ti/	/te/
	Place	/py/	/pu/
		/gø/	/go/
Consonant condition	Place	/ta/	/ka/
		/di/	/gi/
	voicing	/py/	/by/
		/3u/	/fu/

For each of the 16 target words, a 6-sentence passage was created for use in the familiarization phase. The passages were constructed by creating sentences containing the target word either towards the beginning (3) or towards the end (3) of the sentence (Appendix 2.1.). The mean number of syllables in each sentence was 11. Syllables preceding and following the target words in the passages were always different so that no specific syllabic sequence was repeated; this was done to prevent infants from relying on transitional probabilities in order to segment words.

The sentences were recorded by a French-native female speaker in a sound-attenuated booth. She was asked to produce the sentences with mild IDS (infant-directed speech). The passages lasted 16 seconds each. For each syllable the same speaker also produced a list of 20 isolated occurrences for use in the test phase. As for the sentences, she was asked to produce the tokens with some variation to avoid infants' boredom when listening to the lists and also to evaluate recognition of the targets in a condition with some acoustic variability. The sixteen lists lasted 20 s each. Mean values of duration, intensity and pitch of the target words are reported in Table 2.2. for both passages and lists.

Table 2.2. Acoustic measurements of target syllables in passages and lists used in Experiments 9 & 10.

	Words in passages	Words in lists
Duration (ms)	156	310
Intensity (dB)	73,2	73,1
Pitch (Hz)	243	226

Procedure, apparatus and design

The experiment was conducted in a sound-attenuated booth, which contained a three-sided test booth made of pegboard panels. The test booth had a red light and loudspeakers (Sony xs-F1722) mounted on each of the side panels and a green light mounted on the central panel. Directly below the center light, a 5-cm hole accommodated the lens of a video camera used to monitor infants' behavior. A PC computer terminal (Dell Optilex), audio amplifier (Marantz PM4000), TV screen and response box were located outside the sound-attenuated room. The stimuli were stored in digitized form on the computer and were delivered by the loudspeakers via the amplifier. The response box, which was connected to the computer, was equipped with 3 buttons. The box was controlled by an observer, outside the sound-attenuated booth, who watched the video of the infant on the TV screen and pressed the buttons according to the direction the infant's headturns, thus starting and stopping the flashing of the lights and the presentation of the sounds. The observer and the infant's caregiver wore earplugs and listened to masking music over tight-fitting headphones, which prevented them from hearing the stimuli. Information about the direction and duration of the headturns/orientation times were stored in a data file on the computer.

The variant of HPP set up by Jusczyk and Aslin (1994) in their Experiment 3, was used in the present experiment. Each infant was held on a caregiver's lap and the caregiver was seated on a chair at the center of the test booth. Each trial began with the green light on the center panel blinking until the infant had oriented in that direction. Then the center light was extinguished and the red light above the loudspeaker on one of the side panels began to flash. When the infant made a turn of at least 30° in the direction of the loudspeaker, the stimulus for that trial was played, the red light continuing to flash for the entire duration of the trial. Each stimulus was played to completion (i.e., when the six sentences of a given passage had been presented) or stopped immediately after the infant failed to maintain the 30° headturn for two seconds. If the infant turned away from the red light for less than two seconds and then turned back again, the trial continued but the time spent looking away was not included in the orientation time. Thus, the maximum orientation time for a given trial was the duration of the entire speech sample. If for a trial, the infant's orientation time was shorter than 1.5 seconds, the trial was immediately replayed from the beginning and the initial orientation time was discarded.

Each experimental session began with a familiarization phase in which infants heard two passages on alternating trials until they accumulated 30 s of orientation times to each passage. When the infants reached the familiarization criterion for one passage, the second passage continued to be presented until its criterion was also reached. The side of the loudspeaker from which the stimuli were presented was randomly varied from trial to trial. The test phase began immediately after the familiarization criterion was reached. It consisted of three test blocks, in each of which the four lists of isolated syllables were presented. The order of the lists within each block was randomized.

Each infant was assigned to either the consonant or the vowel condition, familiarized with two passages and then tested with the 2 lists corresponding to the target words and the 2 lists corresponding to the mispronounced words. In each condition, each monosyllabic word was used as target for half of the infants and as MP for the other half. Given that 8-month-olds oriented longer to targets than to control words in similar segmentation studies in French (Goyet et al., 2013; Nazzi et al., 2014; Nishibayashi et al., in revision), if infants detect the phonetic changes and treat the MPs as different from the target words, infants should orient longer to the targets than to the MPs. Alternatively, if MPs are assimilated to the target words, infants should orient equally to the MPs and to the target words. With respect to the C-bias, if present at 8 months, infants should orient longer to the targets compared to the C-MPs in the consonant condition, while they should orient equally to the targets and V-MPs in the vowel condition.

1.2.2. Results and Discussion

Mean orientation times were calculated for the lists containing the targets versus the mispronunciations in the two conditions (Figure 2.1.). A 2-way ANOVA with the between subject factor of condition (Vowel vs. Consonant) and the within subject factor of familiarity (Target vs. MP) was conducted. No significant effect was found, neither for the familiarity ($F(1,38) = 0.25$, $p = .62$) nor for the condition ($F(1,38) = 0.98$, $p = .33$) factors. The familiarity x condition interaction was also not significant ($F(1,38) = 1.17$, $p = .29$). This indicates that infants oriented equally to the targets ($M = 6.80$ s, $SD = 2.29$) and the MPs ($M = 6.64$ s, $SD = 2.07$) independently of the condition.

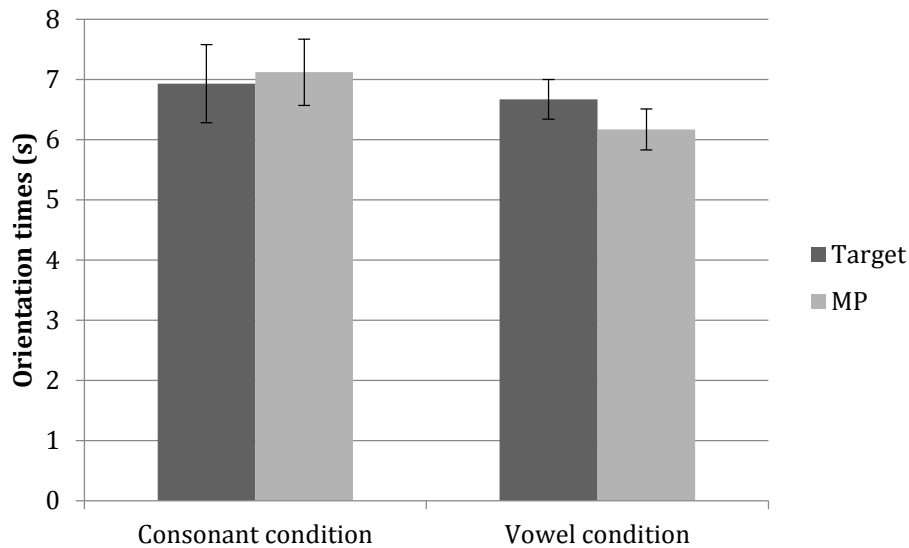


Figure 2.1. Mean orientation times (and SEs) to target vs. MP in Experiment 9 (consonant condition – left panel; vowel condition – right panel).

Contrary to the prediction of the C-bias, we found no evidence that infants could detect the mispronunciations or at last, that their recognition of the target words was affected by mispronunciations, even in the consonant condition. This result is different from evidence by Jusczyk and Aslin (1995) suggesting infants' sensitivity to consonant mispronunciations. Indeed in their study, they found that English-learning 7.5-month-olds failed at the segmentation task when the infants were familiarized with consonant mispronunciations of target words, and then tested on their recognition in passages containing the targets versus control words, suggesting the C-MPs were processed differently than the targets. This difference in result between the two studies might be due to cross-linguistic differences but it might also be due to at least a couple of methodological reasons. The first is that Jusczyk and Aslin (1995) used the word-passage order rather than the passage-word order as we did. The second one is that they presented at test, mispronounced targets versus control words, while we presented correctly pronounced versus mispronounced targets. While it is unclear why reversing the order of passages and words would impact infants' performance in the present task, there is independent evidence suggesting that the second methodological difference could have contributed to the lack of an effect in our experiment. Indeed, Swingley (2005) conducted two sets of experiments on familiar (CVC) word recognition in Dutch-learning 11-month-olds, each having two conditions: Targets (words expected to be known by infants that age) vs. MPs, and Controls (words expected to be unknown to infants that age)

vs. MPs. The first set tested sensitivity to onset consonant MPs and the second tested sensitivity to coda consonant MPs. For onset consonants, infants oriented longer to the targets over the MPs, and oriented equally to the controls and the MPs, a pattern of results suggesting that mispronouncing the onset consonant of the target known words blocked their recognition. However, for coda consonants, infants oriented equally to both targets versus MPs, and controls versus MPs. Swingley (2005) interpreted this pattern of results as indicating that infants were sensitive to the coda mispronunciations (hence the lack of a preference for MPs over controls), but were also noticing the phonological similarity between the targets and MPs, hence the lack of a target preference in that condition.

While there are many differences between Swingley (2005) and our experiment (we tested younger infants, with less knowledge of the phonology and lexicon of their native language, learning a different language, and we used unknown words), his finding suggests that testing infants on MPs versus controls might be a more sensitive way to test infants' sensitivity to mispronunciations. Accordingly, we designed Experiment 10 in which, instead of testing infants on targets versus MPs, we tested them on MPs vs. controls (as done in English by Jusczyk & Aslin, 1995). If testing targets versus MPs (that have a phonetic similarity of 50% in the present experiment) was the source of the null results we observed, a C-bias in Experiment 10 should be marked by a significant preference for MPs in the vowel condition (infants processing the V-MPs as similar to the targets) and no preference in the consonant condition (infants processing the V-MPs as different from the targets, hence as control words).

1.3. Experiment 10: control words vs. mispronunciations at 8 months

1.3.1. Method

Participants

A total of 40 healthy full-term infants were included (14 females and 26 males). They were 8 months of age (mean age: 8 months and 13 days; range: 8 months to 9 months). Six additional infants were tested but not included due to fussiness (1) or crying (3) or a segmentation index (defined as the difference between the mean orientation times to the lists of control and MP) more than 2 SDs above or below the group mean (2). All the infants were from monolingual French-speaking families. All parents gave informed consent before participation and completed an information sheet.

Stimuli

The words, the passages and the lists were the same as in Experiment 9, except that targets were replaced by control words at test.

Procedure, apparatus and design

The apparatus and the procedure was identical to Pilot Experiment while the design was slightly different: infants were familiarized with the same passages but tested with 4 lists, 2 containing the mispronounced target words and 2 containing control words. The rationale is that if infants' recognition of the target is affected by the phonetic change, then the MPs will be considered as different from the target words, and infants will listen equally to MPs and controls. If recognition is not affected by the phonetic change, the MPs will be assimilated to the target words and infants should listen more to the MPs than to the control. With respect to the C-bias, if present, infants should listen equally to the C-MPs and controls in the consonant condition and listen longer to the V-MPs over the controls in the vowel condition.

1.3.2. Results and Discussion

Mean orientation times were calculated for the lists containing the targets versus the MPs in the 2 conditions (Figure 2.2). A 2-way ANOVA with the between subject factor of condition (Vowel vs. Consonant) and the within subject factor of familiarity (MP vs. control) was conducted.

The effect of familiarity was significant ($F(1,38) = 4.51$, $p = .04$, $\eta^2_p = .106$) indicating that infants oriented longer to the MPs ($M = 7.37$ s, $SD = 2.37$) than the controls ($M = 6.79$ s, $SD = 2.11$). The effect of condition did not reach significance ($F(1,38) = 0.10$, $p = .76$). Importantly though, the familiarity x condition interaction was significant ($F(1,38) = 7.53$, $p = .009$, $\eta^2_p = .165$) suggesting that infants behaved differently in the two conditions. To investigate this interaction, we conducted paired t-tests for each condition. In the consonant condition, there was no preference for C-MPs ($M = 6.89$ s, $SD = 2.10$) over controls ($M = 7.06$ s, $SD = 1.54$) words ($t(19) = -0.41$, $p = .68$) with half of the infants having longer OTs for MPs (one-tailed binomial test, $p = .59$). However, in the vowel condition, infants showed a significant preference for MPs ($M = 7.85$ s, $SD = 2.58$) over controls ($M = 6.51$, $SD = 2.56$) words ($t(19) = 3.68$, $p = .002$), with 14 of the 20 infants having longer OTs for mispronounced words (one-tailed binomial test, $p = .058$).

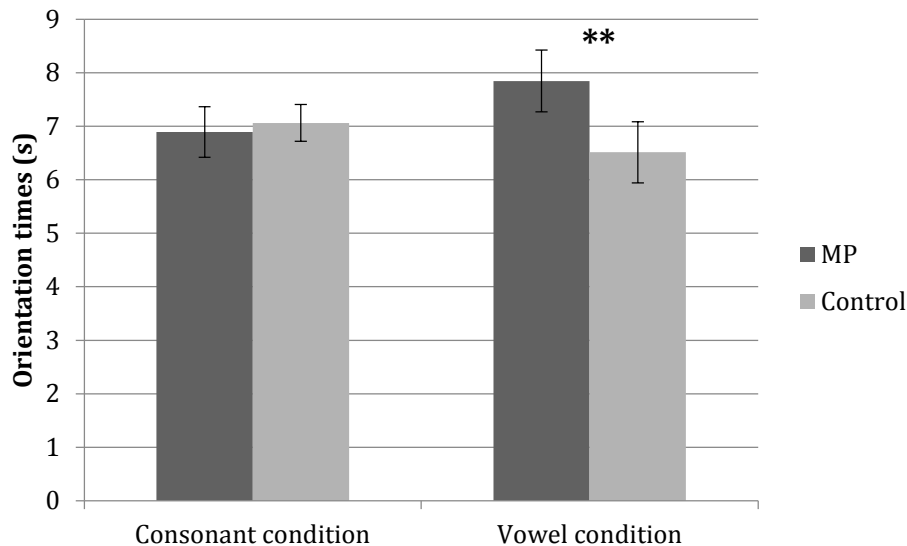


Figure 2.2. Mean orientation times (and SEs) to MPs vs. control words in Experiment 10 (consonant condition – left panel; vowel condition – right panel). ** stands for $p < .005$.

The present results show a segmentation effect in the vowel condition, infants orienting longer to the V-MPs over the control words. This establishes that these infants assimilated the V-MPs to the target words, or at least considered them as good enough pronunciations of the targets. On the contrary, in the consonant condition, infants oriented equally to the C-MPs and the control words, suggesting that they considered the C-MPs as different from the target words. This pattern of findings is compatible with the hypothesis that French-learning 8-month-olds have a C-bias in recognizing segmented word forms.

Why did we not find effects compatible with the C-bias in Experiment 9? The only difference between Experiments 9 and 10 being the phonetic dissimilarity between the words heard in the test phase, we suggest that the absence of significant results in Experiment 9 was due to the difficulty to discriminate or process two phonetically similar words during the test phase.

Importantly, in the present experiment, the C-bias was found using 4 different consonant contrasts and 4 different vowel contrasts, bringing some generality to the present demonstration. However, the C-bias in the present experiment is confounded with a positional effect, since target words were always CV words, hence the consonant mispronunciation always came first and in word initial position, a position privileged according to adult lexical access models (Cohort, Marslen-Wilson, 1987; TRACE, McClelland & Elman, 1986) and that has been found to be better processed by infants in

some studies (Swingley, 2005; Hallé & de Boysson-Bardies, 1996) though not others (Nazzi & Bertoncini, 2009). Although there is some evidence that the C-bias cannot be reduced to a positional effect in adults (New et al., 2008; Delle Luche et al., 2014; Havy et al., 2014), and in some infant studies (Bouchon et al., in revision; Nazzi & Bertoncini, 2009), Experiment 11 was conducted to address this potential confound. We also opted for a structure that would allow us to test the C-bias in a within-subject design, contrary to the between-subject design of Experiment 10 in which infants were never presented with both consonant and vowel mispronunciations, and that established a C-bias through a segmentation effect in the vowel condition and a null effect in the consonant condition found in two different groups of infants.

Accordingly, in Experiment 11, instead of presenting control or target words during the test phase, we used a conflict design as done in studies on phoneme substitution by adults (Cutler et al., 2000; van Ooijen, 1996), new word-object learning by toddlers (Nazzi et al., 2009a; Floccia et al., 2014) or infants (Hochmann et al., 2011), and known word recognition (Pollock & Nazzi, in revision). Therefore, infants were presented in the test phase with both consonant and vowel mispronunciations of a given target (e.g., after being familiarized with a passage containing /do/, they heard both /go/ and /du/). Moreover, to verify that the C-bias obtained in Experiment 10 was not due to a position effect, infants were tested in two conditions: one in which the targets were CV words (the consonant mispronunciations occurring on the onset, hence before the vowel) and one in which the targets were CVC words (the consonant mispronunciations occurring on the coda, hence after the vowel).

1.4. Experiment 11: conflict task at 8 months

1.4.1. Method

Participants

A total of 48 healthy full-term infants were included (23 females and 25 males). They were 8 months of age (mean age: 8 months and 11 days; range: 7 months and 29 day to 8 months and 23 days). Half of the infants were tested in the CV condition and the other half in the CVC condition. Four additional infants were tested but not included due to fussiness (1) or crying (3). All the infants came from monolingual French-speaking families. All parents gave informed consent before participation and completed an information sheet.

Stimuli

Sixteen monosyllabic CV words (/fã/, /fõ/, /du/, /gu/, /sã/, /do/, /sõ/, /go/, /vo/, /py/, /vø/, /by/, /fo/, /pu/, /fø/, /bu/) and sixteen CVC words (/kɔl/, /sik/, /kur/, /set/, /kɔr/, /sit/, /kul/, /sek/, /rys/, /bag/, /ruz/, /bɛk/, /ryz/, /bak/, /rus/, /bɛg/) were selected. All the words were common nouns (except /ruz/ - *Rouze* which is a French town) with relatively low frequencies, as given in the adult database LEXIQUE 3.5 (New et al., 2004, given per 1 million occurrences, and calculated over a base of 31 million occurrences) – /fã/ = 0.54 (*faon* [fawn]), /fõ/ = 376.15 (*fond* [background]), /du/ = 7.16 (*doux* [soft person]), /gu/ = 124.8 (*goût* [taste]), /sã/ = 205.2 (*sang* [blood]), /do/ = 213.99 (*dos* [back]), /sõ/ = 49.32 (*son* [sound]), /go/ = 2.70 (*go* [go game]), /vo/ = 13.92 (*veau* [calf]), /py/ = 0.20 (*pus* [pus]), /vø/ = 10.61 (*voeu* [wish]), /by/ = 51.89 (*but* [aim]), /fo/ = 8.51 (*faux* [fake]), /pu/ = 1.42 (*pou* [louse]), /fø/ = 199.39 (*feu* [fire]), /bu/ = 375.68 (*bout* [piece]), /kɔl/ = 51.82 (*col* [collar]), /sik/ = 0.20 (*sikh* [sikh]), /kur/ = 176.76 (*cours* [course]), /set/ = 0.34 (*set* [placemat]), /kɔr/ = 2.36 (*cor* [horn]), /sit/ = 3.58 (*site* [site]), /kul/ = 0.88 (*coule* [monk mantle]), /sek/ = 0.88 (*sec* [dry]), /rys/ = 15.54 (*russe* [russian]), /bag/ = 16.08 (*bague* [ring]), /ruz/ = 0 (*Rouze* [Rouze – French town]), /bɛk/ = 23.31 (*bec* [beak]), /ryz/ = 13.31 (*ruse* [ruse]), /bak/ = 13.99 (*bac* [bin]), /rus/ = 5.61 (*rousse* [redhead]), /bɛg/ = 0.41 (*bègue* [stutterer]). The words were also chosen so that each word (e.g., /do/) could be used as a target word in the familiarization phase, or as a V-MP (of /du/) or C-MP (of /go/) in the test phase. As a result, across infants, in the CV condition, we used 4 consonantal contrasts (2 voicing and 2 place) and 4 vocalic contrasts (1 roundness, 1 height and 2 place). In the CVC condition, we used the same number of

contrasts (4 for consonant and 4 for vowel) but within the vowel contrasts we used 2 height and 2 place (see Table 2.3. for details).

Table 2.3. Consonant and vowel contrasts manipulated in Experiments 11 & 12 in the CV (up panel) and CVC (down panel) conditions.

CV words					
Vowel	Roundness	/fã/	/fĩ/	/sĩ/	/sã/
	Height	/du/	/do/	/gu/	/go/
	Place	/fø/	/fo/	/vo/	/vø/
Consonant	Place	/by/	/bu/	/py/	/pu/
		/fĩ/	/sĩ/	/fã/	/sã/
	Voicing	/gu/	/du/	/do/	/go/
Consonant	Place	/vø/	/fø/	/vo/	/fo/
		/bu/	/pu/	/py/	/by/
	Voicing				

CVC words					
Vowel	Height	/kur/	/kør/	/køl/	/kul/
	Place	/sæt/	/sit/	/sik/	/sek/
		/rys/	/rus/	/ruz/	/ryz/
Consonant	Place	/bæk/	/bak/	/bag/	/bæg/
		/køl/	/kør/	/kur/	/kul/
	Voicing	/sik/	/sit/	/sæt/	/sek/
Consonant	Place	/rys/	/ryz/	/ruz/	/rus/
		/bag/	/bak/	/bæk/	/bæg/
	Voicing				

For each of the 16 words, a 6-sentence passage was created for use in the familiarization phase. The passages were constructed by alternating sentences containing the target word either towards the beginning (3) or towards the end (3) of the sentence (Appendix 2.2). The mean number of syllables in each sentence was 11. Syllables preceding and following the target words in the passages were always different so that no specific syllabic sequence was repeated; this was done to prevent infants to rely on the transitional probabilities in order to segment words.

The sentences were recorded by a different French-native female talker in a sound-attenuated booth. She was asked to produce the sentences with mild IDS (infant-directed speech). The passages lasted 16 seconds each. For each syllable the same talker also produced a list of 20 isolated occurrences for use in the test phase. As for the sentences, she was asked to produce the tokens with some variations to avoid infants' boredom

when listening to the lists and also to evaluate recognition of the targets in a condition with some acoustic variability. The sixteen lists lasted 20 s each.

Mean values of syllable duration, intensity and pitch are reported in Table 2.4. for both passages and lists.

Table 2.4. Acoustic measurements of target syllables in passages and in lists used in Experiments 11 & 12 (CV: left panel; CVC: right panel).

	CV		CVC	
	Words in passages	Words in lists	Words in passages	Words in lists
Duration (ms)	157	301	255	569
Intensity (dB)	74,4	74,2	74,9	74,5
Pitch (Hz)	247	242	241	231

Procedure, apparatus and design

The procedure and the apparatus were the same as in Experiment 10. Each infant was tested either in the CV condition or in the CVC condition.

Each infant was familiarized with two passages and then tested with 2 lists corresponding to the targets mispronounced on the - onset or coda - consonant (C-MP) and 2 lists corresponding to the targets mispronounced on the vowel (V-MP). Each monosyllabic word was heard as target, C-MP or V-MP, depending on the condition to which infant was assigned. If the C-bias found in Experiment 10 is confirmed, infants' recognition of the segmented word forms should be more affected by the consonant than the vowel mispronunciations, so that they should have longer orientation times to the V-MPs (considered as more similar to the target) than to the C-MPs (considered as more different from the target). If this bias extends to consonants in coda position, this expected pattern should be found both in the CV condition and the CVC condition.

1.4.2. Results and Discussion

Mean orientation times were calculated for the 2 lists containing the C-MPs versus the 2 lists containing the V-MPs in the two word type conditions. A 2-way ANOVA with the between subject factor of word type (CV vs. CVC) and the within subject factor of familiarity (V-MP vs. C-MP) was conducted. The familiarity effect was significant ($F(1,46) = 32.9, p < .001, \eta^2_p = .417$), showing that infants oriented longer to the V-MPs ($M = 8.09$

s, SD = 2.47) than the C-MPs ($M = 6.58$, SD = 2.19). Forty of the 48 infants showed this pattern of preference (one-tailed binomial test, $p < .0001$). Both the effects of word type ($F(1,46) = 3.39$, $p = .07$) and the familiarity x word type interaction ($F(1,46) = 0.21$, $p = .65$) failed to reach significance. This suggests that infants presented a C-bias independently of the type of word (Figure 2.3.), which is confirmed by t-tests conducted in both conditions (CV: $t(23) = 3.62$, $p = .001$, Cohen's $d = .67$; CVC: $t(23) = 4.52$, $p = .0002$, Cohen's $d = .65$).

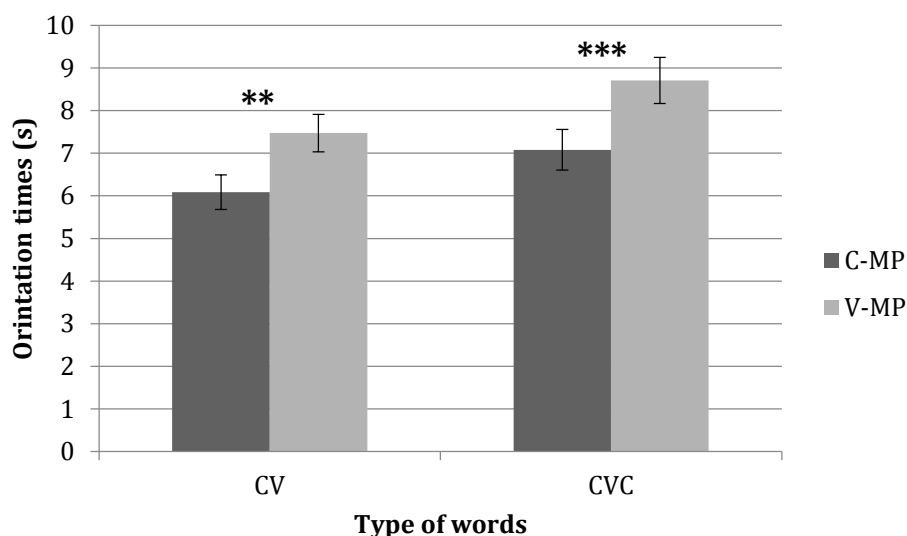


Figure 2.3. Mean orientation times (and SEs) to C-MPs vs. V-MPs at 8 months of age for CV (left panel) and CVC (right panel) words. ** stands for $p < .005$ and *** stands for $p < .001$.

In a within-subject design, the present results show that French-learning 8-month-olds process consonant and vowel mispronunciations differently. Given the familiarity effect (preference for target words over control words) found in Nishibayashi et al. (in press) segmentation study (reported here as Experiment 4), the present preference for V-MPs indicates that infants considered the V-MPs as more similar to the target words heard during the familiarization than the C-MPs. Therefore, the present results confirm the findings of Experiment 10 that at 8 months, French-learning infants have a C-bias in recognizing segmented word forms. As in Experiment 10, this is found using a range of consonantal and vocalic contrasts, hence providing some generality to this finding.

Importantly also, this effect was found independently of the fact that the consonant mispronunciations were before (in onset position) or after (in coda position) the vowel mispronunciations. Therefore, this effect appears to be position independent. The present findings thus provide data relevant to the issue of whether or not consonants are

processed similarly in all syllable/word positions. While some studies found positional effects (Swingley, 2005), the present findings show clear evidence of a C-bias independent of the mispronunciation position (no significant effect of word type), a lack of positional effect also reported in Nazzi & Bertoncini (2009). Note also that Poltrock and Nazzi (in revision) manipulated consonant at medial position of words (CVCV) and found evidence of a C-bias at 11 months. Future research will have to continue exploring this positional issue in order to specify the (task-related, age-related, language-specific) factors that lead to the observation or not of onset/coda effects.

In summary, this is the first time that a C-bias is evidenced at such a young age in all languages tested so far, previous studies having found C-bias effects by 11 months in French (Poltrock & Nazzi, in revision) and 12 months in Italian (Hochmann et al., 2011). Is it possible that a C-bias can be found at an even earlier age, as would be predicted by the initial bias hypothesis (Nespor et al., 2003)? Or, given that Bouchon et al. (in press) found a reversed bias (vowel bias) in a task in which French-learning 5-month-olds had to process consonant or vowel mispronunciations of their own names, does the C-bias appear between 5 and 8 months of age? To explore these questions, and given that Nishibayashi et al. (in press) also found monosyllabic word segmentation at 6 months, also marked by a preference for target over control words (Experiment 4 of present dissertation), Experiment 12 replicated the present experiment with French-learning 6-month-olds.

2. Is the C-bias present at 6 months?

2.1. Experiment 12: conflict task at 6 months

2.1.1. Method

Participants

A total of 48 healthy full-term infants were included (30 females and 18 males). They were 6 months of age (mean age: 6 months and 14 days; range: 6 months to 6 months and 29 days). Half of the infants were tested in the CV condition and the other half in the CVC condition. Six additional infants were tested but not included due to fussiness (3) or crying (3). All the infants were from monolingual French-speaking families. All parents gave informed consent before participation and completed an information sheet.

Stimuli

The target words, the passages and the lists were the same as in Experiment 11.

Procedure, apparatus and design

The procedure, apparatus and design were identical to Experiment 11.

2.1.2. Results

As in Experiment 11, mean orientation times were calculated for the 2 lists containing the C-MPs versus the 2 lists containing the V-MPs. A 2-way ANOVA with the between subject factor of word type (CV vs. CVC) and the within subject factor of familiarity (vowel MP vs. consonant MP) was conducted. The familiarity effect was significant ($F(1,46) = 16.6$, $p = .0002$, $\eta^2_p = .265$), however showing a pattern opposite to the one found in 8-month-olds: 6-month-olds oriented longer to the C-MPs ($M = 8.80$ s, $SD = 2.76$) than the V-MPs ($M = 7.53$ s, $SD = 2.94$). Thirty-six of the 48 infants showed this pattern of preference (one-tailed binomial test, $p = .0004$). Both the word type ($F(1,46) = .57$, $p = .45$) and the familiarity x word type interaction ($F(1,46) = .38$, $p = .54$) failed to reach significance. This suggests that infants presented a V-bias independently of the type of word (Figure 2.4.), which is confirmed by the t-tests conducted in both conditions (CV: $t(23) = -2.25$, $p = .03$, Cohen's $d = -.36$; CVC: $t(23) = -3.67$, $p = .001$, Cohen's $d = -.54$).

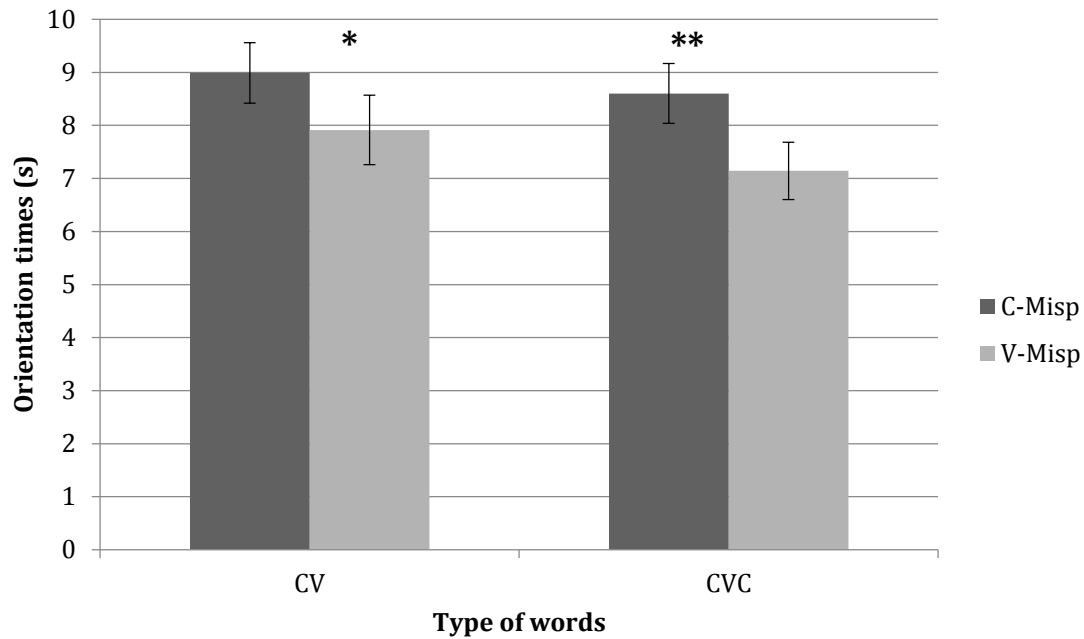


Figure 2.4. Mean orientation times (and SEs) to C-MPs vs. V-MPs at 6 months of age for CV (left panel) and CVC (right panel) words. * stands for $p < .05$ and ** stands for $p < .005$.

Comparison of Experiments 11 and 12 suggests some developmental changes between 6 and 8 months of age. To determine whether these changes are robust, we conducted a further 2-way ANOVA with the factors of age (6 vs. 8 months – Experiments 11 vs. 12) and familiarity (C-MP vs. V-MP). Both the effects of familiarity ($F(1,94) = 0.35$, $p = .56$) and age ($F(1,94) = 2.81$, $p = .10$) failed to reach significance. Importantly though, the familiarity x age interaction was significant ($F(1, 94) = 47.1$, $p < .001$, $\eta^2_p = .334$) confirming that infants behaved differently at 6 and 8 months (Figure 2.5.), infants having a preference for C-MPs and hence a V-bias at 6 months, and a preference for V-MPs and hence a C-bias at 8 months (6 months: $t(47) = 5.79$, $p < .001$, Cohen's $d = .65$; 8months: $t(47) = -4.1$, $p < .001$, Cohen's $d = -.44$).

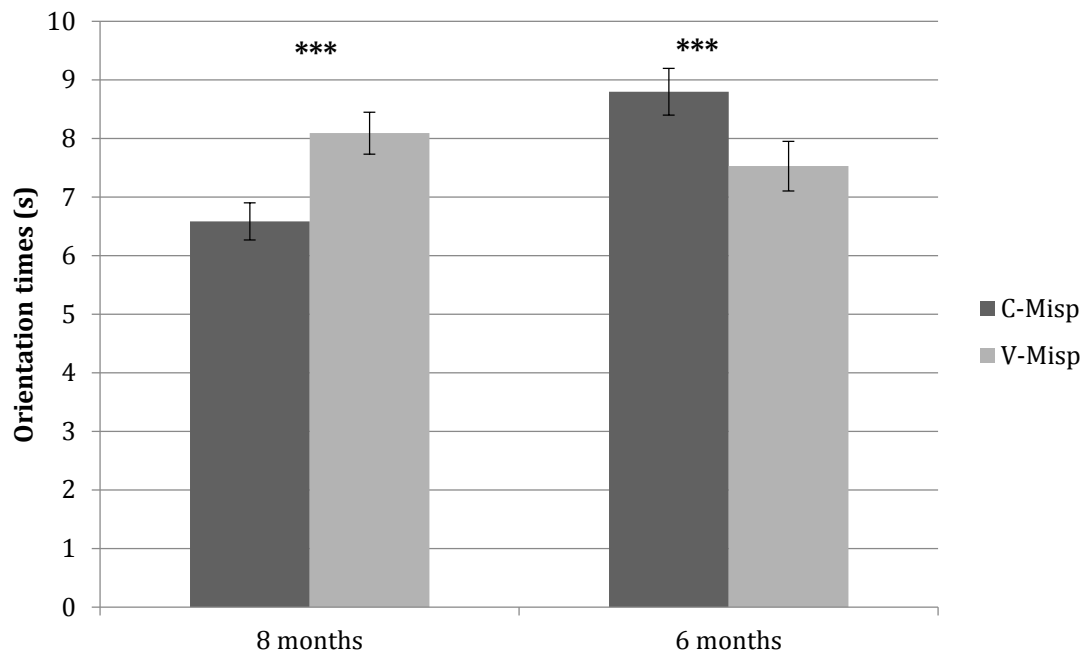


Figure 2.5. Mean orientation times (and SEs) to C-MPs vs. V-MPs in Experiments 11 & 12 at 6 (left panel) and 8 (right panel) months. (***) = $p < .001$

2.2. Discussion

In Experiment 12, 6-month-old infants were tested on both consonant and vowel mispronunciations to determine whether the C-bias found at 8 months extends at a younger age. Results showed that French-learning 6-month-olds also process consonants and vowels differently. However, contrary to the 8-month-olds, the 6-month-olds oriented longer to the C-MPs over the V-MPs. Given the segmentation data obtained in Nishibayashi et al. (in press) using a similar word segmentation procedure and showing a preference for target over control words, the present preference for C-MPs indicates that 6-month-olds considered the C-MPs as more similar to the target words heard during the familiarization phase than the V-MPs. Thus, at 6 months, French infants do not have a C-bias but rather, a vowel bias (V-bias) in recognizing segmented word forms. This pattern of results is in line with the results obtained by Bouchon et al. (in press) in a task exploring familiar word (own name) recognition by French-learning 5-month-olds. Around 5-6 months, French-learning infants thus appear to give more weight to vowels compared to consonants in recognizing both known and unknown (but recently familiarized) words.

3. General Discussion

All present experiments were conducted using HPP in a segmentation paradigm, to investigate whether a functional C/V asymmetry could be observed during the first year of life in French-learning infants. More precisely, this series of experiments was conducted to determine the age of emergence and the origin of the C-bias according to which infants give more weight to consonants than to vowels in recognizing words.

In our study, the presence of a C-bias in French-learning 6- and 8-month-olds was assessed in a single paradigm with a unique word type (that is, unknown words). In all experiments, infants were first familiarized with 2 passages (each containing a target word) and then tested on lists of isolated words. At test, these lists corresponded to target words vs. MPs (Experiment 9), control words vs. MPs (Experiment 10) or C-MPs vs. V-MPs (Experiments 11 and 12). The general rationale was that if infants detect and take into account the phonetic changes, they would consider the MPs as different from the target words heard during the familiarization phase. If they do not detect or if they neglect the phonetic changes, they should consider the MPs as similar to the target words. In order to get results generalizing beyond a single phonetic change, we manipulated, in total, 5 phonetic features: roundness, height and place for vocalic contrasts and voicing and place for consonantal contrasts.

Table 2.5. Summary of the results obtained in Experimental Chapter 2.

	Age (months)	Familiarization	Test phase			Orientation times	Bias?
Pilot Exp. 9	8	Passages	Target	vs.	MP	Target = MP	No
Exp. 10	8		Control	vs.	MP	V-MP > Ctrl C-MP = Ctrl	C-bias
Exp. 11	8		C-MP	vs.	V-MP	C-MP < V-MP	C-bias
Exp. 12	6		C-MP	vs.	V-MP	C-MP > V-MP	V-bias

If the C-bias is present, we expected an asymmetry between consonant and vowel conditions in pilot Experiment 9 and Experiment 10, and between consonant and vowel mispronunciations in Experiments 11 and 12 (see Table 2.5. for an overview of the results).

In pilot Experiment 9, we tested infants on lists of target words versus mispronounced targets (on the consonant or on the vowel). Infants oriented equally to targets and MPs in both consonant and vowel conditions. Given that pilot Experiment 9 failed to provide evidence of a C-bias in recognizing segmented word forms, possibly due to the phonetic similarity between targets and mispronounced targets at test, Experiment 10 tested infants on MPs versus control words, hence cancelling this potential problem of phonetic similarity.

In Experiment 10, French-learning 8-month-olds behaved differently in the two conditions. In the consonant condition, they oriented equally to C-MPs and control words, suggesting that they considered the C-MPs as bad exemplars of the target syllables, hence showing no preference. In the vowel condition, infants looked significantly longer to the V-MPs compared to the control words. Knowing that at 8 months, French-learning infants show a preference for target words in several similar segmentation studies (Goyet et al., 2013; Nishibayashi et al., in press), they might have considered V-MPs as good exemplars of the target words, hence showing a preference for the V-MPs. Experiment 10 thus establishes for the first time a C-bias in French-learning 8-month-olds. Therefore, this finding pushes down to 8 months the evidence of a C-bias in French, where Poltrock and Nazzi (in revision) found it at 11 months. However, Experiment 10 tested infants in a between-subject design: that is, the C-bias was observed with two different groups of infants, the first showing a null effect in the consonant condition and the second showing a segmentation effect in the vowel condition. Poltrock and Nazzi (in revision) in contrast, found a C-bias by presenting infants with both consonant and vowel mispronunciations, hence, showing that 11-month-olds give more weight to consonants over vowels when confronted to both C- and V-MPs.

Therefore, in Experiment 11, we tested 8-month-olds in a conflict task similar to that used in Poltrock and Nazzi (in revision) and Hochmann et al. (2011): infants were tested both on C-MPs and V-MPs of the target words heard during the familiarization phase. Moreover, the C-bias in Experiment 10 could have been due to the position of the MPs, which was always the same (onset consonant MP and final vowel MP) within words. As found by several researchers (e.g., Swingley, 2005), onset and coda consonants are sometimes processed differently. In order to clarify the role of the MP position in our study, Experiment 11 had two conditions: one in which infants were presented with CV words (the C-MP occurring on the onset C) and the other in which infants heard CVC

words (the C-MP occurring on the coda C). The results of Experiment 11 showed that French-learning 8-month-olds orient longer to the V-MPs compared to the C-MPs, suggesting that they considered the V-MPs as more similar to the target words than the C-MPs. Thus, we found evidence of a C-bias in recognizing segmented word forms, infants giving more weight to consonants over vowels, as found in Experiment 10. Moreover, this C-bias was evidenced in both the CV and CVC conditions, suggesting that MP position within a word did not play a role in recognizing segmented word forms.

However, the C-bias should be present earlier than 8 months according to the initial bias hypothesis (Nespor et al., 2003). Experiment 12 thus replicated Experiment 11 with French-learning infants at 6 months of age. Results in Experiment 12 showed that at 6 months, infants listen longer to the C-MPs compared to the V-MPs, hence the pattern opposite to the one found with 8-month-olds. At 6 months, it appears that infants give more weight to vowels over consonants in recognizing segmented word forms, considering the C-MPs as better exemplars of the target words heard in the passages than the V-MPs. Therefore, instead of a C-bias, we observed a V-bias at 6 months. Therefore, it appears that from a V-bias at 6 months, infants switch to a C-bias in processing unknown word forms at 8 months.

Given the most recent studies carried out in French (Bouchon et al., in press; Poltrock et al., in revision), it had been hypothesized that the C-bias might emerge between 5 (evidence of a V-bias) and 11 months (evidence of a C-bias), supporting the acoustic/phonetic hypothesis. However, these previous studies had used different stimuli: infants' own names at 5 months and familiar words at 11 months and it was possible that the observed developmental changes were due to this difference in stimuli. Here, we found evidence of a switch in bias between 6 and 8 months of age in French-learning infants, using the same paradigm and the same stimuli (unknown word forms) at both ages. Our experiments thus bring clear evidence of a switch in bias between 6 and 8 months, confirming what could be indirectly inferred through the comparison of Poltrock and Nazzi (in revision) and Bouchon et al. (in press) findings (respectively a C-bias at 11 months and a V-bias at 5).

Importantly, our findings have implications regarding the origin of the C-bias. Originally, the C-bias was hypothesized to be present cross-linguistically and to be an initial bias (Nespor et al., 2003), hence, present from birth. Later, Keidel et al. (2007) proposed a lexical origin for the C-bias, hence a learned bias reflecting experience with

the lexicon that would provide the knowledge that consonants are more informative than vowels in identifying words. More recently, a third hypothesis was proposed (Floccia et al., 2014) according to which the origin of the C-bias would be acoustic/phonetic, and its emergence would be due to infants' early experience to the acoustic/phonetic properties to their native language. Because the majority of the previous studies exploring the C/V functional asymmetry were conducted in infants during the second year of life, their results could not bring definitive evidence for these competing hypotheses, hence our current study.

The initial bias hypothesis (Nespor et al., 2003) proposes that the C-bias would be present from birth and would be present cross-linguistically. Taken together, Experiments 11 and 12 do not support this hypothesis. Indeed, we found a bias reversal between 6 (V-bias) and 8 months (C-bias) of age in French-learning infants, suggesting that the C-bias would emerge between these two ages. However, in the current study, we did not test younger infants. Thus, the possibility that the C-bias is present from birth cannot be totally discarded since some cognitive mechanisms development follow U-shape trajectories (Marcus et al., 1992; Bowerman, 1982). This is not however the most likely possibility, given data showing the importance of vowels in newborns (Bertoncini et al., 1988; Benavides-Varela et al., 2012).

The lexical bias hypothesis (Keidel et al., 2007) postulates that the C-bias would be learned, thanks to statistical knowledge extracted from the lexicon. Given that Experiments 10 and 11 found evidence of a C-bias at 8 months of age, when they do not have a sizeable lexicon yet, it is less likely that infants could have extracted any lexical information from prior lexical knowledge. Our results thus do not support this hypothesis. However, in our experiments we did not ask parents to evaluate the size and content of their infants' vocabularies (using the French version of the CDI: Kern, 2003, for example). This will be done in a current study that will further explore this issue using ERPs. The CDI data will allow us to investigate the possible link between number of comprehended words and size of the C-bias observed. If a link is present, we expect that the higher the CDI scores, the larger the C-bias found.

Finally, the acoustic/phonetic bias hypothesis (Floccia et al., 2014; Bouchon et al., in press) proposed that the C-bias emerges from early experience to the acoustic/phonetic properties of the native language, hence that the C-bias would be acquired during the first year of life. This hypothesis is supported by Experiments 11 and 12

providing evidence of a switch in bias between 6 (V-bias) and 8 (C-bias) months of age. These results suggest that, between these ages, infants learn from their early experience with speech that consonants are more informative than vowels and make use of this phonological knowledge around 8 months to process words. Before these acquisitions till 6 months, infants would rely on the higher acoustic saliency of vowels even in their processing of words.

How can we account for an initial vowel bias at 6 months (Experiment 12)? Several explanations are possible. First, as mentioned above, vowels are acoustically more salient in the acoustic domain (Repp, 1984; Ladefoged, 2001). At the processing level, this might translate into vowels receiving more weight than consonants during the first six months of life (and might also explain that vowels are acquired before consonants). Second, infants are born with prenatal experience to speech: in the mother's womb, fetuses are exposed to prosodic information (Granier-Deferre et al., 2011). Knowing that prosodic information is mainly carried by vowels, infants at birth, might give more importance to the information they already know (Hunter & Ames, 1988; Hunter, Ross, & Ames, 1982).

Then, from a V-bias (vowel saliency reliance), through experience to acoustic/phonetic properties of the speech signals, infants would gradually learn that consonants are lexically more informative than vowels, to finally reach an adult-like C-bias in recognizing segmented word forms (Experiment 11 at 8 months). Several explanations might justify this switch. First, consonants are perceived more categorically than vowels (Fry et al., 1962; Liberman et al., 1957), hence might be more discriminable. This is supported by data from Bouchon et al. (in press) showing that consonants are more distinctive than vowels when normalized in duration and intensity. Second, given that the inventory of consonants of the native language is acquired later (10-12 months; Werker & Lalonde, 1988; Werker & Tees, 1984) than the inventory of vowels (6 months; Kuhl et al., 1992; Polka & Werker, 1994), 8-month-old infants might begin to have access to this salient discriminability information, and might move from an acoustic/phonetic to a phonological level of processing, resulting in a C-bias in processing word forms. Third, even if our data do not support Keidel et al (2007), there is a way to reformulate their lexical bias hypothesis, in which the C-bias would not be learned from the lexicon, but from a proto-lexicon of word forms learned from infants' ability to segment word forms from continuous speech from at least 6 months of age. Future studies will have to specify this proto-lexicon and determine whether analyses of this proto-lexicon similar to those

done for the adult lexicon by Keidel et al. (2007) would also show the greater informativeness of consonants than vowels.

Taken together, the experiments described in Experimental Chapter 2 are the first to clearly demonstrate developmental changes in phonological biases used in lexically-related processing. It appears that from a vocalic reliance at 6 months, infants switch to a more adult-like consonant reliance at 8 months. These phonological changes occur therefore in parallel with the acquisitions of vowels and consonants inventories (see Figures 0.1. and 4.1). In the future, since our experiments investigated the C-bias only in French-learning infants, more cross-linguistic studies will have to be conducted in infants before their first birthday in order to see whether and how the present developmental scenario extends to other languages.

In light of the findings of Experimental Chapter 2 and previous studies conducted to specify the origin of the C-bias, we suggest the following cross-linguistic predictions:

- Although Floccia et al. (2013) did not find evidence of a C-bias in older toddlers, we expect that English-learning infants would show the same pattern as French-learning infants, if tested with our simpler procedure: a V-bias at 6 months and a C-bias at 8 months (Experiment 10 is currently being replicated in Amanda Seidl's lab, Purdue University).
- In contrast, we expect a different pattern in Danish-learning infants. Since Danish-learning 20-month-olds were found to have a V-bias while French-learning 20-month-olds were found to present a C-bias in the same task, we hypothesize that Danish infants would not have any switch in bias during the first year of life: accordingly, from a vowel saliency bias at 6 months, we expect Danish-learning 8-month-olds to present a vowel phonetic bias in processing segmented word forms. Thus rather than a switch in bias we expect a switch in V-bias status (acoustic/phonetic → phonological).

GENERAL DISCUSSION AND PERSPECTIVES

To study how language is learned, many researchers addressed this issue by cutting it into smaller questions such as how and when prosodic and phonetic discrimination abilities emerge or become language-specific. Thanks to this developmental approach, many answers have been provided. For example, and for our concern, we now know that newborns at birth are already sensitive to subtle prosodic and phonetic cues and differences (Bertoncini et al., 1987; Mehler et al., 1988; Nazzi et al., 1998; Ramus, 2002). Then, from this initial sensitivity, infants were found to acquire the prosodic (Höhle et al., 2009; Jusczyk et al., 1999) and phonetic (Kuhl et al., 1992; Polka & Werker, 1994; Werker & Tees, 1984) properties of their native language. This phenomenon of specialization to the native language is called perceptual attunement. If such perceptual attunements exist, they must have an impact on early language-related abilities at higher linguistic levels.

The present dissertation explored the processes by which infants acquire their first word forms and how recognition of these forms is influenced by early perceptual biases and attunements. To investigate these topics, we focused on the use of rhythmic units in early segmentation and on the emergence of the consonant bias (C-bias) in early word form recognition by French-learning infants during the first year of life. Being able to segment continuous speech is crucial to extract and learn the words of the native language. Furthermore, the C-bias was proposed to help infants in their first developmental steps to acquire and recognize new words (Nespor et al., 2003). While Experimental Chapter 1 explored when and how segmentation abilities emerge, Experimental Chapter 2 looked at the origin of the C-bias by studying sensitivity to mispronunciations in segmented word form recognition in French-learning infants.

1. What we learned from our studies

1.1. Rhythmic units and word form segmentation

Many cues have been identified to help speech segmentation. Among those, the role of transitional probabilities have been largely explored and have been determined to help segmentation in adults (Saffran et al., 1996a) and infants (Pelucchi et al., 2009; Saffran et al., 1996b) with both artificial and natural utterances. Other cues such as allophonic variations (Jusczyk et al., 1999b) and phonotactic regularities (Gonzalez Gomez & Nazzi, 2013; Mattys et al., 1999) have been found to facilitate word segmentation. However, following Jusczyk et al. (1999a), many studies have been investigating another important cue: the rhythmic unit. The original work of Jusczyk et al. (1999a) showed that English-learning infants appear to use some rhythmic regularities of the words of their native language to extract early word forms. While English-learning 10.5-month-olds were found to segment both trochaic and iambic bisyllabic words, 7.5-month-olds could only segment trochaic words. Because the trochaic pattern at the word level is the predominant stress pattern in English, this result suggests a developmental trajectory in English-learning infants' segmentation abilities: from an initial sensitivity to prosody from birth, infants appear to learn the predominant stress pattern of their native language to extract words from sentences. Similar developmental changes were found for Dutch (Kooijman et al., 2009, 2013) suggesting that infants acquiring a stress-based language acquire the trochaic units to segment continuous speech. What about the use of the syllabic unit, the rhythmic unit of French, for infants acquiring a syllable-based language?

Nazzi et al. (2006) explored syllabic segmentation in French-learning 8-, 12- and 16-month-old infants and found a similar pattern in terms of use of rhythmic units to that of Jusczyk et al. (1999): from no segmentation at 8 months to a syllabic segmentation at 12 months, infants segment bisyllabic words as whole units at 16 months. Thus, Nazzi et al. (2006) proposed the rhythmic segmentation hypothesis to explain this developmental change. According to this hypothesis, infants would begin to segment continuous speech by using the rhythmic unit of their native language. Because syllable-based language units are syllabic units, French-learning infants should use the syllabic units to segment speech. However, while Jusczyk et al. (1999a) found trochaic unit segmentation in English-learning infants as early as 7.5 months of age, syllabic segmentation was only observed

by 12 months in French-learning infants (Nazzi et al., 2006). Nazzi et al. (2014) found that this lag was partly due to methodological reasons: if familiarized with passages and then tested with words in isolation (passage-word order) contrary to the word-passage order used in Nazzi et al. (2006), French-learning 8-month-olds were found to segment bisyllabic words. The passage-word order thus helped infants extracting words. One possibility to explain this finding is that TP availability is not the same between the two orders. In the passage-word order, TPs are available at the beginning of the test phase whereas in the word-passage order, they become increasingly available as the test phase advances. First, it appears that infants can combine rhythmic units and TP cues. Second, the availability (or the weight) of the TPs can influence the observation of a syllabic segmentation in French-learning infants.

Therefore, following these findings, Experiments 1-3 (Goyet, Nishibayashi, & Nazzi, 2013) of the present dissertation explored the role of syllabic units along with TPs in French-learning 8-month-olds. Results showed that 8-month-olds could segment embedded syllables, hence use syllabic units, but only when TPs around the target syllables were drastically decreased. These findings confirm the fact that French-learning infants do use syllabic units to segment speech and suggest that tracking syllabic units depends on the weight of the TPs, suggesting a combined use of TPs and syllabic units to segment speech.

Syllabic segmentation being established by Experiments 1-3 at 8 months in French-learning infants, we explored how early syllabic units are used to segment speech. Thus, in Experiments 4-7 (Nishibayashi, Goyet, & Nazzi, in press), we explored the role of syllabic units in French-learning 6-month-old infants. Under the same conditions of marked reduction of the TPs (which was shown as the optimal condition to observe syllabic segmentation at 8 months, Experiment 3), 6-month-olds were found to segment monosyllabic words (Experiment 4) and embedded syllables (if familiarized longer, Experiment 6) but not whole bisyllabic words (Experiment 7). Recall that bisyllabic words are segmented at 8 months (Nazzi et al., 2014) in French-learning infants under a more difficult condition (shorter familiarization). Thus, these findings provide evidence of an earlier use of syllabic units to segment speech at 6 months. Importantly, while 6-month-old infants were found to segment monosyllabic words, they needed longer familiarization to segment embedded syllables. One possible explanation for this finding

is that coarticulation around the target syllables is not the same in the monosyllabic word and embedded syllable conditions, leading to facilitated monosyllabic word segmentation.

Taken together, Nazzi et al. (2014) and Nishibayashi et al. (in press) establish a developmental pattern in the kind of word forms French-learning infants can extract: from monosyllabic word and embedded syllable segmentation at 6 months, infants become able to segment whole bisyllabic words at 8 months. At the rhythmic unit level, this developmental pattern is similar to the one shown by Jusczyk et al. (1999a) in English. Therefore, Experiments 1-7 provide evidence that French-learning infants use the rhythmic unit of their native language (syllabic units) in early segmentation. These findings are congruent with evidence of syllabic segmentation in Catalan and Spanish (Bosch et al., 2013) which are two other syllable-based languages. Together with the data showing the use of the rhythmic unit of stress-based languages (trochaic unit) in English and Dutch (Jusczyk et al., 1999a; Kooijman et al., 2009), our data support the early rhythmic bootstrapping hypothesis (Nazzi et al., 2006).

Unfortunately, we could not test younger infants because of the HPP set-up we use in our laboratory. Indeed, the red lights are located at 180° on the right and left panels, hence preventing infants with non-mature motor skills (i.e., 4-month-olds) to successfully turn their heads during the experiment. To explore whether even infants younger than 6 months can segment syllabic units, one solution would be to use the slightly modified version of the HPP set-up used at 4 months by Herold et al. (2008), in which all three lights are located on the same front panel, hence limiting infants' head movements.

Little is known about how rhythmic units are learned and start being used for segmentation. Because of its prosodic nature and because prosody is heard *in utero*, rhythmic units could be learned from both pre- and post-natal experience. To investigate this possibility, Experiment 8 was conducted in replication of Experiment 4, with healthy very preterm infants (gestational age between 26 and 33 weeks). Because these preterm infants had been deprived of nearly three months of prenatal exposure to prosody, we predicted that preterm infants might not be able to segment monosyllabic words given a possible developmental lag in acquiring their native rhythmic unit, provided that monosyllabic words are mainly/solely segmented based on the use of rhythmic units (although we discussed the possible influence of coarticulation at 6 months to explain the difference of results obtained between Experiments 5 and 6). Experiment 8 showed that overall, preterm 6-month-olds were able to segment monosyllabic words, hence that they

show no delay compared to full-term infants at the same age (Experiment 4). Two explanations are possible. First, if preterm birth impacts the acquisition and use of rhythmic units, the segmentation effect in Experiment 8 might be due to the fact that the preterm infants used other cues to segment monosyllabic words (such as coarticulation). A second possibility is that all rhythmic units might not be equal. As suggested by Bijeljac-Babic et al. (1993) showing that newborns are able to detect a change in the number of syllables of the words composing two lists, the syllable might be a basic processing unit, which might be used at the onset of word segmentation without being a rhythmic unit. According to this second possibility, from birth, French-learning infants might use the syllable as a basic unit. Then, receiving no additional relevant rhythmic properties such as a trochaic stress pattern like in English, they might specify the syllable as the rhythmic unit of their native language. Thus, preterm infants would not be delayed in monosyllabic word segmentation because they might use the syllable as a basic unit while full-term infants at the same chronological age might use the syllable as a rhythmic unit.

Although our preterm results are interesting (in particular in light of preterm segmentation failure reported by Bosch, 2011), this experiment is not completed yet. Indeed, because more than half of the infants we tested were from bilingual families, additional infants will need to be added in both monolingual and bilingual groups. Furthermore, in Experiment 8, we excluded the preterm infants that could not turn their heads correctly. Hence, we do not know whether these infants we excluded could segment monosyllabic words. Another experimental procedure will have to be used to explore whether preterm infants with insufficient motor skills can segment speech.

One possible developmental pattern fitting our results (Figure 3.1.) is that initially, infants are cross-linguistically sensitive to the basic syllabic unit. Then, around 6-8 months, by prosodic attunement and statistical computations on the speech input, they acquire the rhythmic units of their native language and start using it to segment words that follow this rhythmic unit (e.g., trochaic unit for English, Dutch and German; syllabic unit for French, Spanish and Catalan). Then, after a few more months of exposure to speech, they start segmenting more complex words (e.g., iambic pattern for English, bisyllabic units for French) using a combination of different cues. In French, infants might be sensitive to the basic syllabic unit from birth and around 6 months of age, acquire its rhythmic status. Of course, we cannot evaluate these possibilities till other languages are tested in the syllable-, stress- and mora-based classes.

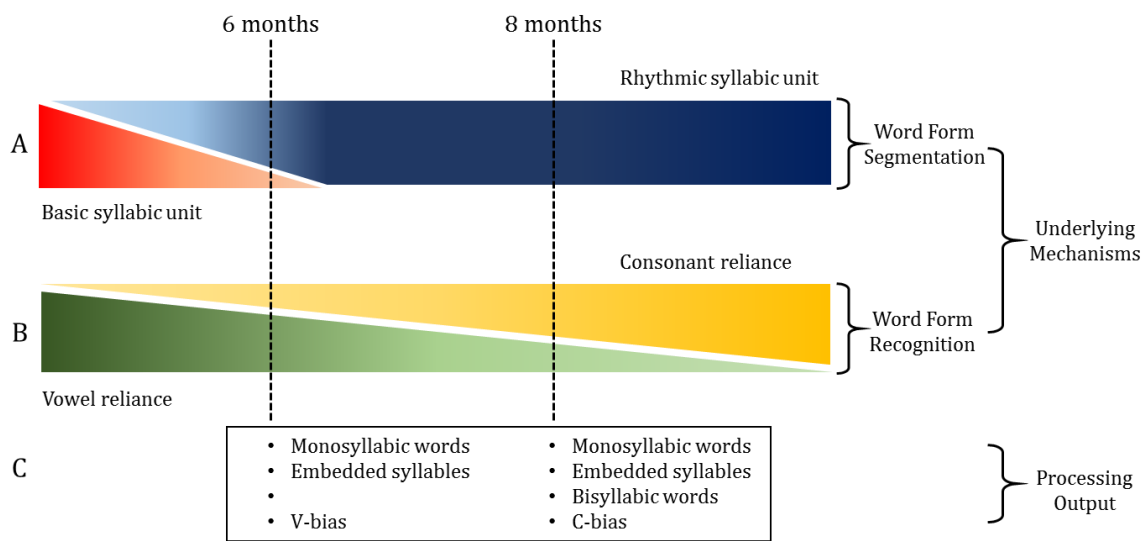


Figure 3.1. Possible developmental patterns in word form segmentation (A) and C-bias emergence (B) in French-learning infants according to our results (C).

1.2. Emergence of the C-bias during the first year of life in French-learning infants

According to Nespor et al. (2003), consonants and vowels would play different functional roles in early language acquisition: consonants would be more involved in lexical processing (C-bias) and vowels in prosodic and syntactic processing (V-bias). Furthermore, Nespor et al. (2003) proposed a language-general initial bias hypothesis according to which the C-bias would be cross-linguistically present from birth. Alternatively, Keidel et al. (2007) proposed the learned lexical bias hypothesis according to which the C-bias would be acquired from the structure of the lexicon. Analyzing the structure of the lexicon allow to discover that consonants are more informative than vowels, hence the emergence of a C-bias when toddlers have acquired a large enough lexicon. A third hypothesis was proposed by Floccia et al. (2014) and Bouchon et al. (in press): the learned acoustic/phonetic bias hypothesis which postulates that the C-bias would emerge from the early experience to the acoustic/phonetic properties of the native language. In this hypothesis, the C-bias would emerge during the first year of life, before infants learn a sizeable lexicon. Due to their nature, the lexical hypothesis (Keidel et al.,

2007) and the acoustic/phonetic hypothesis (Bouchon et al., in press; Floccia et al., 2014) predict cross-linguistic differences in the emergence (or the absence) of the C-bias.

Evidence of a C-bias was found in adults speaking French, Dutch, English, and Spanish (Cutler et al., 2000; Delle Luche et al., 2014; New et al., 2008; New & Nazzi, 2014; van Ooijen, 1996) but the trajectory of its emergence differs depending on the language being acquired. While the C-bias was consistently found in French-learning toddlers by 11 months onward (Havy & Nazzi, 2009; Nazzi, 2005; Nazzi et al., 2009a; Poltrock & Nazzi, in revision) it was neither the case for English-learning toddlers who were found to have a C-bias at 15 and 30 months (Mani & Plunkett, 2007; Nazzi et al., 2009a) but not at 12 (Mani & Plunkett, 2010), 16, 18, and 24 months (Floccia et al., 2014; Mani & Plunkett, 2007), nor for Danish-learning 20-month-olds (showing a V-bias, Højen & Nazzi, in revision). The fact that the C-bias is not consistently found cross-linguistically does not support the language-general C-bias hypothesis (Nespor et al., 2003).

Moreover, Poltrock and Nazzi (in revision) found evidence of a C-bias in French-learning 11-month-olds when they were tested in a familiar word recognition task. In contrast, Bouchon et al. (in press) found a V-bias at 5 months in French-learning infants when they were tested on the recognition of their own names. Taken together, these two studies suggest that the C-bias appears between 5 and 11 months of age in French-learning infants. However, Bouchon et al. (in press) and Poltrock and Nazzi (in revision) used different types of stimuli (infant's own names in the former and familiar count nouns in the latter), so that the difference in biases in these two studies might be an artefact of having used different stimuli. Therefore, knowing that infants can segment monosyllabic words at 6 and 8 months of age (Nishibayashi et al., in press), we directly explored whether the C-bias appears during the first year of life in segmented word form recognition, by using the same type of stimuli (unknown words) and the same experimental procedure as in Experiment 4 of the present dissertation.

Experimental Chapter 2 (Experiments 9-12) was composed of a series of experiments investigating whether segmented monosyllabic word recognition is disrupted if mispronounced either on a consonant or on a vowel. The C-bias was successfully observed at 8 months of age: segmented word recognition was disrupted when the target words were mispronounced on consonants but not on vowels (Experiment 10). In Experiment 10, infants were presented with either vowel or consonant mispronunciations. Thus, in Experiment 11, we presented each infant with

both consonant and vowel mispronunciations of the target words (within-subject design). When tested with such a conflict situation, 8-month-olds considered the consonant mispronunciations as more different from the target words than the vowel mispronunciations. Thus, Experiments 10 and 11 provide consistent evidence of a C-bias in early word form recognition. Given that Bouchon et al. (in press) found evidence of a V-bias at 5 months, Experiment 12, replicating Experiment 11, tested infants at 6 months. Results showed that French-learning 6-month-olds present the opposite pattern compared to the 8-month-olds, namely a V-bias.

This pattern of findings establishes the emergence of the C-bias during the first year of life, as was suggested by the comparison of Bouchon et al. (in press) and Poltrock and Nazzi (in revision), and has implications for the different hypotheses proposed for its acquisition. First, it does not support the initial bias hypothesis (Nespor et al., 2003) according to which the C-bias is present at birth, since we did not find it at 6 months (although we did not test younger infants). Second, it does not support a strong version of the lexical bias hypothesis (Keidel et al., 2007) according to which the C-bias emerges from the structure of the lexicon. Indeed, infants at 6 and 8 months do not have a sizeable lexicon yet, even if they know the meaning of a few words at 6 months (Bergelson & Swingle, 2012; Tincoff & Jusczyk, 1999, 2012): according to Kern (2007), only 16 words are comprehended by 50% of French-learning 8-month-olds. However, our findings might still be explained by the sophisticated analysis proposed by Keidel et al. (2007) but conducted at the level of the protolexicon rather than at the level of the lexicon, and resulting in acquiring that consonants are more informative than vowels to distinguish words. Finally, our findings support the acoustic/phonetic bias hypothesis (Bouchon et al., 2014; Floccia et al., 2014) according to which infants acquire a C-bias (or a V-bias) through early experience to the acoustic/phonetic properties of their native language. From an acoustic reliance on vowels at 6 months, infants would acquire a C-bias around 8 months of age which would affect how they recognize segmented word forms (Figures 3.1. & 3.2.).

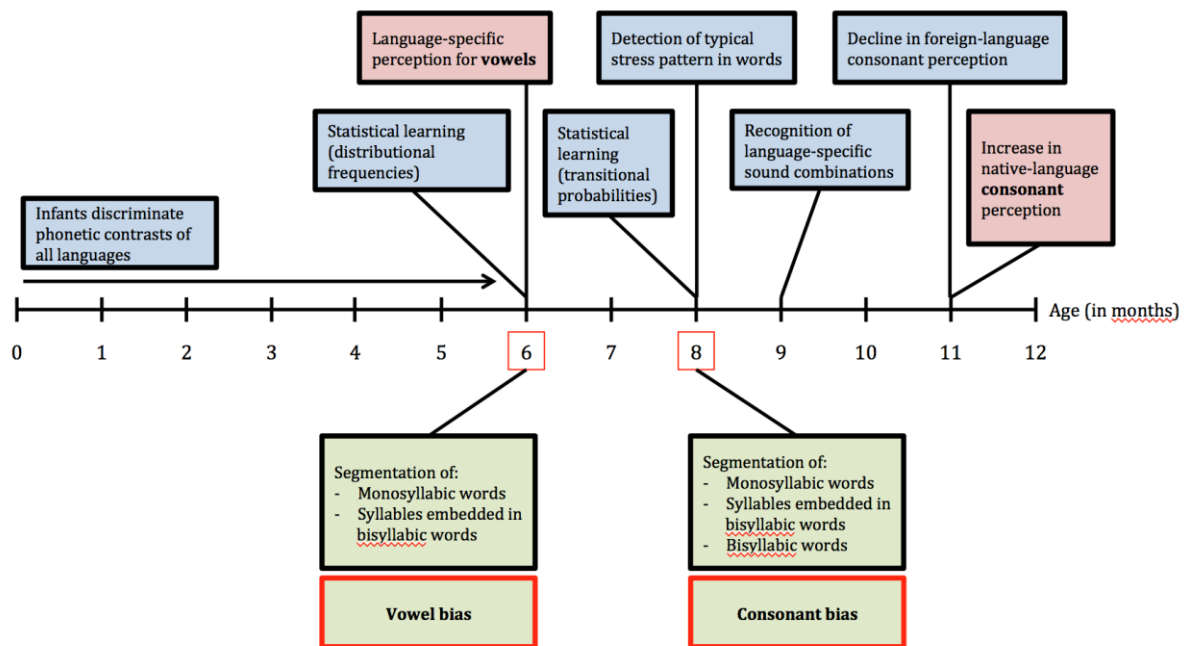


Figure 3.2. Results obtained in the present dissertation placed within the timeline of speech perception development proposed by Kuhl (2004).

In summary, we found evidence that infants begin using the rhythmic unit of their native language to segment words around 6 months, age at which they process their segmentation outcomes by relying more on the vowel information they carry. Prosody being mainly carried by vowels, initial sensitivity and acquisition of the prosodic properties of the native language might enhance the V-bias found at 6 months in French-learning infants. Then, around 8 months, infants begin to segment bisyllabic words thanks to syllabic units and other cues such as TPs and will process these segmented forms by preferentially relying on the higher informativeness of consonants, acquired from early experience to the acoustic/phonetic or proto-lexical properties of their native language.

2. Theoretical frameworks

In this section, we discuss our findings in relation to different developmental models that have been proposed to account for early language acquisition.

2.1. Perceptual Assimilation Model (Best, 1995)

Best (1995) proposed a model to explain how adults organize the perception of nonnative categories according to their native categories: the Perceptual Assimilation Model (PAM). According to PAM, the ease for perceiving nonnative contrasts should be predictable from differences in the patterns of gestural similarities and disparities between nonnative and native phonemic distinctions. In PAM, there are four distinct discrimination cases according to whether adults will assimilate or not a nonnative contrast to one or two phonemes of their native language. First, the two phonemes of a nonnative contrast may be assimilated to two different native phonemes (Two Categories, TC). Second, they may both equally or poorly assimilate to a Single native Category (SC). Third, they may both be assimilated to a single native category, but one may be more similar than the other to the native phoneme (Category Goodness, CG). Fourth, the nonnative sounds may be too discrepant from the gestural properties of any native categories to be assimilated (Non Assimilable, NA). Accordingly, adults will be able to discriminate nonnative phonemes in the TC or NA cases, while they will have difficulties in the SC or CG cases. This model was initially proposed for consonantal phoneme perception without taking into account vowels.

In terms of development, knowing that infants were found to specialize their consonant perception into a language-specific mode between 6-8 months and 10-12 months of age (Werker & Tees, 1984), Best (1995) proposed a developmental pattern according to which until 6-8 months of age, infants would initially perceive speech sounds driven by simple acoustic/articulatory distinctions (and this ability would not be influenced by the linguistic environment yet), and between 8 and 10 months, they would start perceiving speech sounds on the basis of the phonetic patterns of their native language that they are in the process of acquiring. The recognition of these patterns might still be under-specified and infants will compare less frequent phonemes to good exemplars they already stored. According to this developmental scenario, around 6-8

months of age, infants would discriminate two word forms solely on the basis of acoustic/gestural saliency. However, in our studies, we observed that between 6 and 8 months of age, infants change the way they recognize segmented word forms: 6-month-olds give more weight to vowels while 8-month-olds give more weight to consonants. To explain this pattern of results, we proposed that infants might rely more on vowels due to their acoustic saliency until 6 months and that between 6 and 8 months of age, they start relying more on consonant higher distinctive nature which would have been extracted from experience with the acoustic/phonetic and proto-lexical properties of their native language. Thus, contrary to Best (1995) who proposed that the linguistic environment start influencing infants' speech perception of consonants between 8 and 10 months of age, our results suggest that this linguistic shaping might have started earlier, between 6 and 8 months of age, in our infant population.

How can we explain this possible difference? Note that the majority of studies on phonetic attunement were conducted in English-learning infants (for a review, see Jusczyk, 1997), while our series of experiments were carried out only in French-learning infants. The fact that we found an earlier influence of the native linguistic environment might be due to the difference in the languages at test. This idea is supported by the fact that Hoonhorst, Colin, Markessis, Radeau, Deltenre, and Serniclaes (2009) found that French-learning 8-month-olds are already attuned to the native properties of voice onset time (VOT) in their native language. Such evidence of an earlier acquisition of native phonetic patterns in French-learning infants might also explain the lack of evidence of a C-bias in English-learning toddlers (Floccia et al., 2014; Mani & Plunkett, 2007, 2010). Therefore, further studies will be needed during the first year of life to determine whether the early emergence of the C-bias that we found in French-learning infants can be found in infants acquiring other languages.

2.2. Native Language Neural Commitment (Kuhl, 2000, 2004)

Based on our findings, we propose that early experience to the acoustic and phonetic properties of speech explains the emergence of two fundamental abilities: 1) the use of native rhythmic units (the syllabic segmentation in French) for word segmentation and 2) the preferential use of consonant information (C-bias) in early word processing.

According to the Native Language Neural Commitment (NLNC) theory proposed by Kuhl (2000, 2004), early language learning (such as prosodic and phonetic learning) will shape brain development, by specializing its function for the processing of the native language. As a consequence, as the brain specializes for native language perception and processing, sensitivity to other nonnative information would decrease. Given that we found developmental changes at the behavioral level in French-learning infants during the first year of life, we expect related changes at the brain level, which might be revealed by testing infants using ERPs and observing potential changes in the ERP signatures of word form segmentation and detection of mispronunciations of segmented word forms.

Such segmentation ERP signatures were found by Kooijman et al. (2005, 2009, 2013) in Dutch-learning infants during the first year of life, at 7 and 10 months. Two different segmentation signatures were found, that differed in terms of polarity, suggesting developmental changes in segmenting speech from a less mature positive-going response to a more mature negative-going response. Since a similar negative-going response for segmentation was found in French-learning 12-month-olds (Goyet et al., 2010), it would be interesting to determine the kind of response (negative or positive) observed for the segmentation of different types of word forms at different ages in French. Furthermore, this electrophysiological method allows testing younger infants. Accordingly, if French-learning infants start processing speech driven by basic syllabic units from birth as we proposed, before learning to use syllables as rhythmic units, a change in the neural response of segmentation might occur at some point between birth and 6 months of age.

ERPs could also be measured to explore how infants detect consonant and vowel mispronunciations. Since we found a switch in bias ($V \rightarrow C$) when recognizing segmented word forms, we can expect a related switch in neural responses to consonant and vowel mispronunciations between 6 and 8 months of age in French-learning infants, with more mature responses at 8 months.

Furthermore, the NLNC hypothesis (Kuhl, 2000, 2004) takes into account the fact that infants' early skills in native language processing would predict later children's language-related skills. In other words, early speech perception abilities in infancy would bootstrap word learning and later syntactic and semantic processing. Kuhl, Conboy, Padden, Nelson, and Pruitt (2005) explored whether this hypothesis is correct with a discrimination task in which English-learning 7-month-olds were first presented with

native (English) and nonnative (Mandarin) contrasts and then tested later (14, 18, 24 and 30 months) on their language abilities. Results showed that 1) at 7 months, infants who had better abilities in discriminating the native contrast had poorer abilities in discriminating nonnative contrast, thus showing a negative correlation between native and nonnative phonetic discrimination abilities; 2) infants who had better discrimination abilities for the native contrast at 7 months had better language abilities at older ages. These findings support the NLNC hypothesis (Kuhl, 2000, 2004) according to which learning mechanisms result in a commitment of the neural networks to the native patterns of speech and that infants' early ability to attune to their native language predicts later language skills. Similar findings were obtained at a higher level, showing that early segmentation abilities predict later language-related skills (Junge et al., 2012; Kooijman et al., 2013; Newman et al., 2006).

With respect to the present dissertation findings, using ERPs could allow us to relate infants' early segmentation capacities with later language development. Given Kooijman et al. (2013), we predict that French-learning 8-month-old infants with a more mature segmentation signature (negative-going response) will have better language skills by the second year of life. Furthermore, because the C-bias was observed at 8 months but not at 6 months, hence establishing early phonetic attunement in recognizing segmented word forms, the emergence of the C-bias might also predict later language skills: the earlier the C-bias emerges and the stronger it is, the better infants' later language skills might be. Thus, at the brain level, we expect that the type of neural responses signaling the detection of mispronunciations might predict later language skills. More precisely, if we do find more mature responses to mispronunciations in 8-month-olds, we expect infants having more mature neural responses when detecting consonant and vowel mispronunciations to have better later skills during childhood.

2.3. Processing Rich Information from Multidimensional Interactive Representations (Werker & Curtin, 2005)

Our results can also be discussed within the theoretical framework proposed by Werker and Curtin (2005): Processing Rich Information from Multidimensional Interactive Representations (PRIMIR). PRIMIR is a model in which the use of the rich information contained in speech depends on the joint activity of three dynamic processing filters on three different planes of representations. The first filter corresponds to initial biases such as preference for speech sounds, IDS and proper syllable form. The second filter corresponds to the developmental level of the infant and the third one corresponds to the specific language-learning task. These three filters will enhance or diminish raw physical saliency of the signal (e.g., acoustic, phonetic saliencies) and are coupled with general learning mechanisms (GLM; described in terms of computational skills by Kuhl, 2004). These filters ensure that infants will only learn linguistically possible utterances. The joint action of these filters gives birth to three different planes: the General Perceptual, the Word Form and the Phonemic planes. The General Perceptual plane contains all the speech information representation such as phonetic and prosodic information, but also indexical information. Within this plane, information itself will be categorized through attunements (e.g., prosodic and phonetic attunements) to the native language in acquisition: prosodic and phonetic units are represented into clustering neighborhoods on the basis of similarity of features. Then, language-specific categories help infants form the Word Form plane which contains the representations of extracted utterances that form cohesive units (that do not have meanings). Note that cohesive units do not mean distinct units at the beginning. Indeed, word forms are organized in clusters overlapping along phonetic features. In this plane, word forms are stored and represented as individual exemplars that will cluster. Once infants have stored a sufficient number of meaningful words, the Phonemic plane emerges. In this plane, phonemes are defined by their function of distinguishing two phonetically similar words that have different meanings.

The present dissertation provided evidence of syllabic segmentation in infants as young as 6 months of age, using the rhythmic unit of French, the syllable. Thus, the Word Form plane has already emerged at this age and should contribute in attuning speech sound representations at the General Perceptual plane. To account for the acquisition of

the rhythmic unit of the native language which we hypothesized to occur before 6 months of age, we propose to enrich the Phonemic plane so that it would include not only the different native phonemes but also other phonological information such as the rhythmic pattern of the native language, and hence to rename it the Phonological plane. Thus, around 6 months of age, infants would learn the rhythmic segmentation unit of their native language and represent it at the Phonological plane. That way, PRIMIR would also be able to account for the learning of native prosodic patterns (including rhythmic units but also lexical tones). Knowing that PRIMIR postulates interactions between the different planes, we propose a developmental pattern to explain how infants develop their segmentation abilities. First, at birth, French newborns would store all the raw speech information within the General Perceptual plane and at that level, they would use the syllabic unit as a basic unit of representation. The representation of this basic unit would allow infants to detect a change of number of syllables between two utterances (Bijeljac-Babic et al., 1993). Second, between birth and 6 months of age, infants would learn the rhythmic unit of their native language and represent it in the Phonological plane. Then, rhythmic units would influence how speech sounds are represented in the General Perceptual plane, allowing infants to track rhythmic units within sentences to successfully segment word forms that would then be represented in the Word Form plane. Third, between 6 and 8 months of age, infants would strengthen their segmentation abilities by combining rhythmic units with other cues (e.g., phonotactic regularities, TPs, allophonic variations) that would also be represented in the Phonological plane.

How can we view our results showing the emergence of the C-bias between 6 and 8 months of age in French-learning infants within the PRIMIR framework (Werker & Curtin, 2005)? First, the vowel advantage in processing word forms at 6 months could emerge from the interaction between the different planes. In the General Perceptual plane, among all the information contained in speech, vowels are acoustically more salient than consonants and the filters coupled with the General Learning Mechanisms (GLM) would enhance this saliency. Since infants were found to start acquiring their native vowel inventory around 6 months of age, the Phonological plane at this age would contain some vocalic phonemes that would further enhance the vowel discrimination abilities at the General Perceptual plane. Thus, the vowels of familiar (Bergelson & Swingley, 2012; Tincoff & Jusczyk, 1999, 2012) and unfamiliar word forms would be given more weight than consonants at the Word Form plane. The interaction of the three planes would thus

elicit a V-bias in recognizing segmented word forms. At 8 months, infants having started to acquire the consonant inventory of their native language, some consonant phonemes would be represented at the Phonological plane. Then, the filters would diminish vowel acoustic saliency at the General Perceptual plane and the GLM would lead to consonant higher informativeness by analyzing the structure of the protolexicon (lexicon of the word forms that have been extracted) at the Word Form plane (note that Keidel et al., 2007, proposed a similar analysis but of the lexicon). As the protolexicon grows, the Phonological plane would have more and more influence on the other planes and the interaction of the three planes might elicit a C-bias in recognizing segmented word forms at 8 months of age. Accordingly, Figure 4.3. illustrates the slightly modified version of PRIMIR we propose and match the results we obtained in Experimental Chapters 1 and 2.

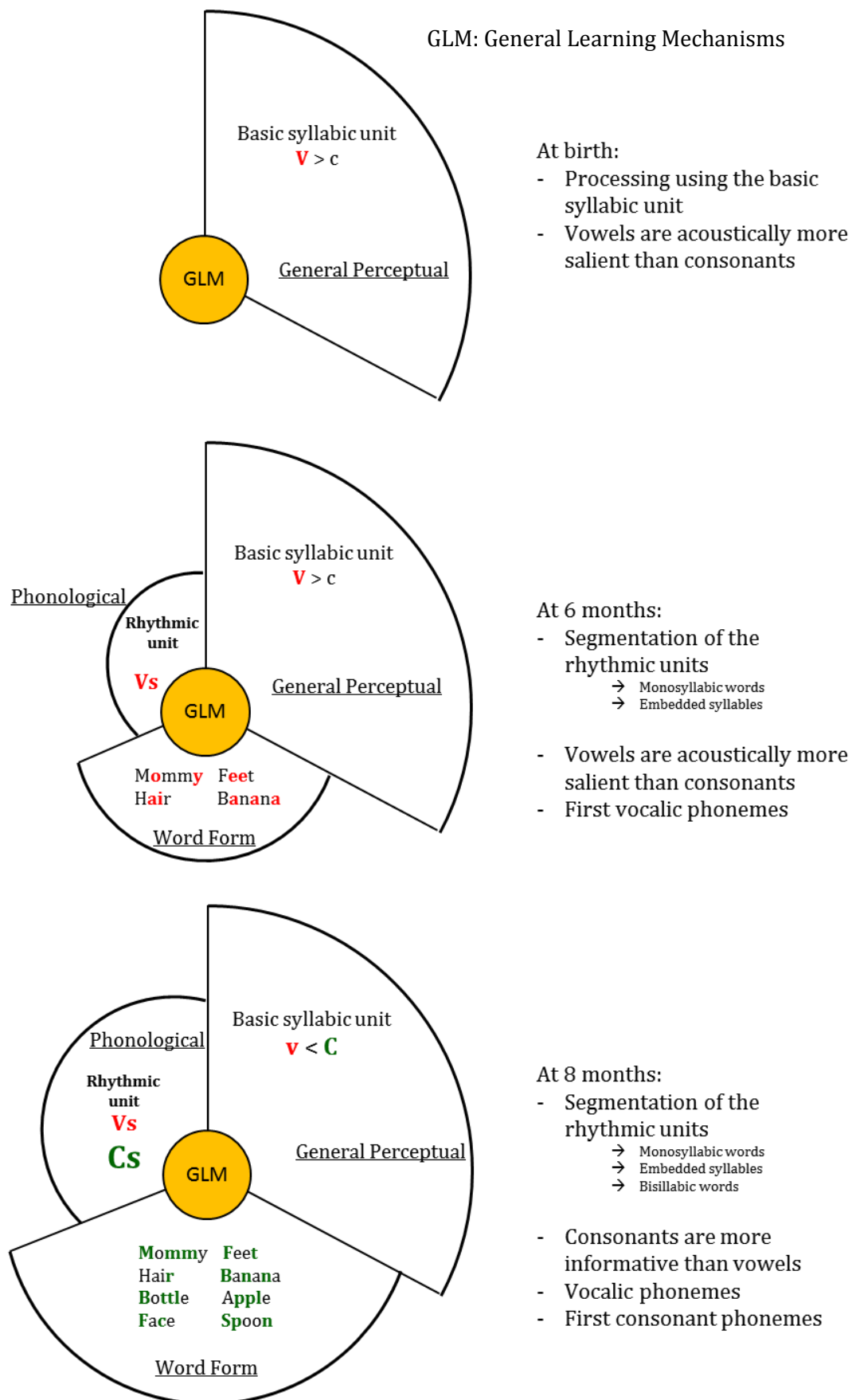


Figure 3.3. Proposal of a developmental pattern in processing segmented word forms by French-learning infants according to PRIMIR (Werker & Curtin, 2005).

3. Perspectives

In the preceding sections, we discussed our results, proposed some interpretations and sketched some perspectives. In the following, we provide some ideas about follow-up experiments to this dissertation.

3.1. Directions for future studies on word segmentation

Experimental Chapter 1 provided evidence that French-learning infants are using their native rhythmic unit, the syllabic unit, to segment the speech stream, supporting the rhythmic segmentation hypothesis (Nazzi et al., 2006). However, our findings only concern French-learning infants. Thus, to support this interpretation of our findings, further studies are first needed to explore whether the use of rhythmic units follows the same developmental pattern in languages beyond those studies so far (English, Dutch, French, Spanish and Catalan). It will also be important to conduct further segmentation studies in different rhythmic classes (e.g., Japanese for mora-based languages).

Second, because sensitivity to number of syllables was observed in newborns (Bijeljac-Babic et al., 1993), one can expect that newborns are cross-linguistically sensitive to the syllabic unit as a basic unit of speech perception. Accordingly, we propose that initially, segmentation will be syllable-based cross-linguistically. A first possibility to test this hypothesis would be to investigate segmentation abilities in infants younger than 6 months in the three rhythmic classes (stress-, syllable- and mora-based languages). The idea is that at some point, between birth and 6 months of age, if infants use the syllable as a basic unit, monosyllabic word segmentation should be observed cross-linguistically even if it does not correspond to the native rhythmic unit. A second possibility would be to investigate whether preterm infants at 6 months can segment embedded syllables in the same condition as in Experiment 6. If they are not able to segment embedded syllables which full-term infants can do, it would mean that the preterm infants in Experiment 8 segmented monosyllabic words by relying on a language-general basic syllabic unit.

Third, knowing that segmentation abilities were also demonstrated using ERPs (Kooijman et al., 2005, 2009, 2013), we are currently setting up a new experiment that will use ERPs to study segmentation procedures. Six- and 8-month-old infants will be

familiarized with passages and then tested on segmented word form recognition. As Kooijman et al. (2013), we expect infants to have different ERP signatures for word segmentation depending on their level of language acquisition: with a less mature positive-going response for 6-month-olds and a more mature negative-going response for 8-month-olds. This series of experiments will give us the opportunity to investigate how syllables are used in French-learning infants to segment continuous speech and further investigate when the use of syllabic unit as rhythmic unit emerges by testing younger infants.

Fourth, segmentation abilities were found to be good predictors for later word recognition, comprehension and production (Junge et al., 2012; Kooijman et al., 2013; Newman et al., 2006). Thus, to explore whether earlier acquisition of the rhythmic syllabic unit predicts better comprehension at a later age, one possibility would be to systematically ask parents to fill the French CDI (Kern, 2003) when infants are in the lab, and again later at 24 months of age. This can be done in both behavioral and electrophysiological studies (this will be done in the ERP study we are currently setting up).

Furthermore, the experimental design of our ERP study will also allow the investigation of the emergence of the C-bias in French-learning infants between 6 and 8 months, as we describe in the next section.

3.2. Directions for future studies on the C-bias

Our studies showed the emergence of a C-bias between 6 and 8 months of age in French-learning infants. According to the acoustic/phonetic bias hypothesis (Bouchon et al., in press; Floccia et al., 2014) which our findings support, the acoustic/phonetic properties of the native language being acquired by infants might predict when the C-bias emerges or not. If the language being acquired has a well-balanced C/V ratio like French, in which consonants are more informative for early word form recognition, a C-bias might emerge similarly to what we observed in French-learning infants. For a language in which consonants are consequently more numerous than vowels (e.g., Russian and Tashlhiyt, according to the World Atlas of Language Structures – WALS online, Maddieson, 2013), the C-bias might emerge even earlier or might be stronger. In languages having more vowels than consonants (e.g., Swedish and Danish), we expect no switch in bias between

6 and 8 months of age, but rather a switch in the status of the V-bias. Infants acquiring Swedish or Danish, might first rely on the acoustic saliency of vowels and then change into a more phonetic/phonological reliance on vowels. Consequently, our conflict situation (consonant mispronunciation vs. vowel mispronunciation – Experiments 11 & 12) should be replicated in each of the three scenarios we propose. Note that we are collaborating with Amanda Seidl and Yuanyuan Wang (Purdue University) and they are currently conducting an English version of our Experiment 10 (mispronounced targets vs. control words) with English-learning 6- and 8-month-olds.

The ERP experiments we are setting up also allow the investigation of the emergence of the C-bias in French-learning infants during the first year of life. We will familiarize infants on 6-sentence passages containing monosyllabic target words and then test them on three types of list: correctly pronounced target words, vowel mispronunciations (V-MPs) and consonant mispronunciations (C-MPs). First, knowing that French-learning infants segment monosyllabic words at 6 and 8 months of age, we expect a change in the responses to the target words during the familiarization phase between the first two and the last two sentences, as found by Kooijman et al. (2013) for Dutch (although they familiarized infants with isolated syllables and not passages). In the test phase, response patterns to correctly pronounced target words will serve as a baseline (ERP signature of segmentation) against which we will compare ERP responses to V- and C-MPs. Our behavioral data suggest that the infants might have considered (or recognized) the mispronunciations as close (V-MPs at 8 months and C-MPs at 6 months) or different (C-MPs at 8 months and V-MPs at 6 months) to the familiarized target words. Thus, at 8 months, infants might have a segmentation-like signature for V-MPs but not for C-MPs and the opposite at 6 months. However, the neural response for C- and V-MPs might also reflect infants' ability to detect a mispronunciation rather than the ability to recognize the familiarized word (Mani et al., 2012, showing a neural response for V-MPs). All in all, we expect the neural signatures for mispronunciations to differ between 6- and 8-month-old infants depending on whether it is the consonants or the vowels that are mispronounced. More precisely, we expect a significant interaction between the age (6 vs. 8 months) and the type of mispronunciation (consonant vs. vowel). If such an interaction emerges, we will be able to determine the neural signature for both consonant and vowel biases.

With the ERP experiments, as Kooijman et al. (2013) showing that segmentation abilities predicts later language skills, we will also investigate whether the emergence of the C-bias could predict later comprehension skills. This investigation will be two-fold. First, we will ask parents to fill the French CDI (Kern, 2003) at 8 months. Infants will be divided into two groups determined by lower and higher comprehension scores. If the neural signature of the C-bias is successfully determined, we expect that its pattern might differ depending on the comprehension score obtained at 8 months. Second, we will ask parents to fill another CDI when the infants are 24 months old so that we will be able to determine whether the type of neural pattern for the C-bias predicts later word comprehension.

To sum-up, the ERP project will allow us to study both segmentation abilities and the emergence of the C-bias in lexical processing in French-learning infants. Moreover, it will allow us to investigate how syllabic units are used and whether the emergence of the C-bias predicts later language-related skills.

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APPENDICES

Appendix 1.1. Passages used in the familiarization phase of Experiments 1 & 2.

/ba/ passage

Ce bassin mérite d'être mieux nettoyé. Ce tuba fait partie des plus sûrs. J'aime regarder ces bassins gris. Personne ne doit toucher à mes tubas bleus. Il nettoie les cinq bassins lentement. Vous avez trouvé leurs tubas trop grands. Ces deux bassins sont faciles à remplir. Les tubas sont ajustés soigneusement.

/di/ passage

Mille divas ont chanté sur cette scène. Ils serviront cent radis roses. Mes amis connaissent plusieurs divas mariées. Huit radis restent dans cette assiette. Les divas quittent ce bel opéra. Ton père a apporté le radis salé. Il aime écouter cette diva russe. Cinq radis noirs sont dans le bol.

/tʃ/ passage

Les tombeaux noirs ne sont pas à la mode. Elle s'est contentée de ce jeton noir. Il y a douze tombeaux pillés. Les jetons peuvent être achetés. Certains tombeaux forment un triste décor. Elle a misé tous ses jetons gris. Nous trouvons ce tombeau fabuleux. Huit jetons ne rentrent pas très bien.

/pu/ passage

Les poulains noirs vont galoper. Il a dansé sur un quipou indien. Le garçon fait trotter le poulain mouillé. La danse quipou s'apprend parfois à l'école. Deux poulains seront vendus lundi. Ces quipous sont faciles à danser. Je lui ai dit de choisir trois poulains vifs. Ces filles veulent danser le quipou indien.

Appendix 1.2. Passages used in the familiarization phase of Experiment 3.

/di/ passage

Le dîner mondain m'ennuie horriblement. Leurs caddies contiennent beaucoup de denrées. Il lui a écrit un dizain romantique. Il vient d'arrêter cinq bandits dangereux. Tes deux divans rouges sont très confortables. Votre taudis vient d'être découvert. L'homme doit écouter deux ditos moralisants. J'aime manger ces deux radis salés.

/gu/ passage

Le goulot de la bouteille est brisé. Notre dégoût de la viande est surmonté. Il prépare un goujon citronné. Elle déguste ce bon ragoût cuisiné. Quelques gourous les influencent dangereusement. Les cagous ont des plumes argentées. Vous découpez des tranches de gouda salé. Vous trouvez parfois que son bagou dérange.

/po/ passage

Vos poneys broutent dans le pré. Quelques capots rouges sont froissés. Les filles raffolent de potins crapuleux. Les meubles sont rangés dans un dépôt scellé. Ton pommeau de douche est cassé. Notre topo a convaincu l'assemblée. J'ai rempli notre pochon de cerises. J'ai besoin de plus de repos en hiver.

/te/ passage

Trop de télé abrutit les enfants. J'habite près des cités des arts. J'ai marché sur un tesson de bouteille. J'ai acheté trois pâtés en croute. Quelques têtus sont dans cette classe. Le synthé lui sera offert à Noël. Les veaux boivent aux tétons de leur mère. Il existe quatre comtés dans la région.

Appendix 1.3. Passages used in the familiarization phase of Experiments 4 & 7.

/di/ passage

Ce dit énoncé est bien formulé. J'aime quand il narre plusieurs dits imagés. Les dits annonceurs du mage sont à craindre. Elles ne relatent que quatre dits mensongers. Leurs dits ne doivent pas être entendus. J'ai appris quelques dits sur lui. Quatre dits sont prononcés par la femme. L'homme vocifère de nombreux dits contre lui.

/po/ passage

Trois pots bleus sont bien suffisants. Je mets quelques pivoines dans ce pot vert. Quelques pots en grès sont en vente. J'aimerais trouver quatre pots dans le jardin. Mes pots rouges en terre sont cassés. Il recycle ses pots contenant certains cornichons. Vos pots de yaourt se recyclent. Au marché cinq pots d'olive sont offerts.

/te/ passage

Le thé est une boisson savoureuse. Le matin je bois du thé au lait. Boire deux thés me réveille plus facilement. Je ne consomme que certains thés anglais. Certains thés sentent vraiment très bon. Ma fille aime sucrer son thé vert. Certains thés ne se trouvent qu'au marché. Tu n'achètes que ton thé en boîte.

/gu/ passage

Le goût de ces cerises m'enchant. La fille n'aime pas le goût sucré. Ces goûts exquis et savoureux me plaisent. L'enfant se régale au goût de la crème. Mon goût préféré est celui de la menthe. L'alimentation varie selon les goûts de chacun. Nos goûts favoris sont le citron et le café. Au fur et à mesure nos goûts évoluent.

Appendix 1.4. Passages used in the familiarization phase of Experiments 5 & 6.

/di/ passage

Le dîner mondain m'ennuie horriblement. Leurs caddies contiennent beaucoup de denrées. Il lui a écrit un dizain romantique. Il vient d'arrêter cinq bandits dangereux. Tes deux divans rouges sont très confortables. Votre taudis vient d'être découvert. L'homme doit écouter deux ditos moralisants. J'aime manger ces deux radis salés

/po/ passage

Vos poneys broutent dans le près. Quelques capots rouges sont froissés. Les filles raffolent de potins crapuleux. Les meubles sont rangés dans un dépôt scellé. Ton pommeau de douche est cassé. Notre topo a convaincu l'assemblée. J'ai remplis notre pochon de cerises. J'ai besoin de plus de repos en hiver.

/te/ passage

Trop de télé abrutit les enfants. J'habite près des cités des arts. J'ai marché sur un tesson de bouteille. J'ai acheté trois pâtés en croute. Quelques têtus sont dans cette classe. Le synthé lui sera offert à Noël. Les veaux boivent aux tétons de leurs mères. Il existe quatre comtés dans la région.

/gu/ passage

Le goulot de la bouteille est brisé. Notre dégoût de la viande est surmonté. Il prépare un goujon citronné. Elle déguste ce bon ragoût cuisiné. Quelques gourous les influencent dangereusement. Les cagous ont des plumes argentées. Vous découpez des tranches de gouda salé. Vous trouvez parfois que son bagou dérange.

Appendix 1.5. Passages used in the familiarization phase of Experiment 7.

/bādi/ passage

Le bandit appelait ses complices barbus. Je me défendais contre des bandits verts. Ces bandits ont braqué les bijouteries. Tu as rencontré un bandit aimable. Certains bandits font amende honorable. Les policiers cherchaient plusieurs bandits rouges. Quelques bandits se sont précipités dehors. L'avocat écoute les bandits repentis.

/kapo/ passage

Ce capot ne s'ouvre que de l'arrière du véhicule. Nous réparerons demain un capot troué. Des capots s'entassent par centaine de milliers. Vous allez certainement croiser le capot bleu. Notre capot laisse sortir beaucoup de fumée. J'ai admiré ce matin ces capots neufs. Plusieurs capots ont été envoyés à la casse. Tu leur aurais envoyé trois capots lustrés.

/ʒøte/ passage

Ce jeté a battu le précédent record. Ils n'esquiveront jamais nos jetés francs. Des jetés ont permis l'obtention de droits. Nous recevrons de plein fouet le jeté direct. Certains jetés arrivent à dépasser la ligne. Vous allez me filmer ces jetés longs. Quelques jetés pleuvent encore au-dessus. Je calcule la vitesse d'un jeté droit.

/ragu/ passage

Le ragoût de ma grand-mère est délicieux. Le cuisinier mijote les ragoûts salés. Ce ragoût me replonge en petite enfance. Leur préférence ira au ragoût sucré. Ces ragoûts laissent un souvenir mémorable. Les sans-abris mangent quelques ragoûts chauds. Votre ragoût est digne d'apparaître à l'Elysée. Je tomberai sur certains ragoûts amers.

Appendix 2.1. Passages used in the familiarization phase of Experiments 9 & 10.

/py/ passage

Le pus est annonciateur d'infection sanguine. Le docteur a examiné son pus jaune. Ce pus sera de mauvais augure à ce stade. Le genou écorché a produit du pus sanguin. Tout pus a disparu de ces blessures de guerre. Il est tombé et son coude suinte d'un pus coulant.

/ʒu/ passage

Le joug du roi s'étend jusqu'aux bordures de seine. Ils plient de douleur sous leur joug impérial. Un joug dictatorial est encore en place en chine. Les paysans se rebellent contre ce joug princier. Mon joug s'est affirmé au cours de ces années. Un dirigeant a mis en place son joug électoral.

/by/ passage

Le but est de trouver le dernier élément. Je ne sais pas si j'atteindrai mon but premier. Son but semble bien malhonnête à première vue. Ils ne savent jamais quels sont leurs buts nobles. Ce but n'est pas louable dans cet hôpital. Vous ne voulez pas connaître ces buts cachés.

/ʃu/ passage

Ce chou est un aliment bon pour la santé. Je trouve que ça sent fortement le chou ici. Un chou peut désigner un petit enfant. Les garçons naissent dans des choux de Bruxelles. Les bouts de chou sont très mignons en crèche. Les adultes et les enfants n'aiment pas les choux fleurs.

/ta/ passage

Le tas de boue est idéal pour le compost. Vous n'êtes pas du tout prêt de lire ce tas de livres. Un tas peut regrouper une dizaine de cartes. Avec mes jouets je vais faire un tas très haut. Les tas des pierres à la plage sont faits avec des seaux. Les couvertures de l'asile sont pliées en tas rangés.

/di/ passage

Ce dit énoncé est souvent bien formulé. J'aime quand il narre plusieurs dits imagés. Les dits annonciateurs du mage sont à craindre. Elles ne relatent que quatre dits mensongers. Leurs dits ne doivent pas être entendus par les parents. L'homme vocifère de nombreux dits contre lui.

/ka/ passage

Son cas à l'accusé s'est aggravé aujourd'hui. Elle travaille sur une étude de cas banale. Un cas peu commun s'est présenté à l'hôpital. Vous irez à l'école dans tous les cas possibles. Dans certains cas il peut se montrer souple. Souvent il fait beau mais ce n'est pas le cas ici.

/gi/ passage

Un gui est un arbrisseau qui porte chance. Elle m'a embrassé sous le gui de chez elle. Son gui sert d'ornement durant la fête de Noël. Les baies jaunes proviennent du gui du sapin. Ce gui comme le houx se voit souvent à Paris. En médecine on utilise certains guis pour soigner.

Appendix 2.2. Passages used in the familiarization phase of Experiments 11 & 12.

CV condition:

/fã/ passage

Le faon a perdu sa maman biche dans le bois. Les écologistes ont pris soin des faons peureux. Un faon court très vite dans le pré familial. Les chasseurs ont ramené quelques faons savoureux. Les faons doivent survivre aux prédateurs carnivores. Ce point d'eau accueille plusieurs faons apeurés.

/du/ passage

Les doux vivent heureux et toujours souriants. La bonté se ressent chez ces doux russes. Un doux est attendu à la réception. Des sages ont encensé ce doux courageux. Certains doux sont écoutés pour leurs conseils. Parfois ils ont pensé à devenir doux rouge.

/fõ/ passage

Un fond marin peut être étudié en quelques mois. Tu pourras me donner des fonds sympathiques. Le fond de la tasse est entaché de café noir. J'étudie depuis longtemps ce fond acoustique. Les fonds d'écran changent toutes les cinq minutes. Son ordinateur possède certains fonds très moches.

/gu/ passage

Le goût des cerises m'enchanté énormément. La fille aux nattes n'aime pas du tout le goût sucré. Ces goûts exquis et savoureux me plaisent beaucoup. L'alimentation varie selon les goûts de chacun. Mon goût préféré est celui de la menthe fraîche. Au fur et à mesure nos goûts évoluent.

/sã/ passage

Mon sang semble aussi bleu que celui du roi. Il avait peur et s'est fait un sang d'encre. Le sang est surtout composé d'hémoglobine. Les hématies sont responsables du rouge sang humain. Du sang neuf coule dans la grande seringue stérile. Les seiches possèdent des vaisseaux pleins de sang noir.

/do/ passage

Le dos courbé il s'acharne sur sa faible proie. Je vois un médecin pour mon mal au dos persistant. Un dos musclé peut s'obtenir avec cette machine. Au camping on peut voir quelques dos blancs. Leurs dos sont marqués de coups de fouet répétés. La nuit tombe et on ne distingue plus les dos meurtris.

/sõ/ passage

Le son du clocher avoisine ta voix de crécelle. Le glas de l'église fait éclater un son terne. Des sons étranges proviennent de l'ancre du dragon. J'écoute dans le métro du son qui

bouge. Ce son est pour le moins inhabituel en campagne. Il émet du gosier certains sons amusants.

/go/ passage

Le go de mon père est fait en bois laqué. On leur a distribué plusieurs go gratuits. Un go est offert au gagnant du concours. J'ai rencontré des joueurs de go formidables. Ce go me vient de mon ancêtre japonais. Tu as retrouvé la trace de certains go rares.

/vo/ passage

Le veau de lait est délicieux en cette saison. J'aurais préféré un ris de veau poivré. Ce veau vient de naître dans la ferme voisine. La vache vient de mettre bas d'un petit veau blanc. Un veau gambade dans le nouvel enclos de Georges. Le jeune fermier s'occupe de ses veaux avec amour.

/py/ passage

Du pus sortit de ses nombreuses plaies béantes. Les enquêteurs ont trouvé des traces de pus séché. Son pus a été enlevé par des antibiotiques. Tes blessures ne montrent plus un pus jaunâtre. Le pus se présenta de l'éraflure de tout le coude. Ils ont toujours prélevé leur pus au centre.

/vø/ passage

Mon vœu le plus cher est la paix dans le monde. Leurs dieux pourront accorder trois vœux innocents. Ce vœu est réalisable par le mage bleu. Tu vas avoir droit à des vœux incroyables. Un vœu sera souhaité au cours de la nuit. Les génies donnent le choix entre deux vœux magiques.

/by/ passage

Le but est de trouver le dernier élément. Je ne sais pas si j'atteindrai mon but premier. Son but semble bien malhonnête à première vue. Ils ne savent jamais quels sont leurs buts nobles. Ce but n'est pas louable dans cet hôpital. Vous ne voulez pas connaître ces buts cachés.

/fo/ passage

Ce faux a été découvert au musée. Il est difficile de distinguer le faux du vrai. Son faux fut démasqué par la police. Je veux savoir lequel est un faux tout de suite. Leur faux est bien dissimulé dans les bois. Interpol a mis la main sur ton faux hier.

/pu/ passage

Les poux sont redoutés dans les maternelles. Je sais comment enlever ces poux hargneux. Le pou est très résistant aux shampoings normaux. Tu aurais dû éviter d'attraper des poux bruns. Leurs poux ne sont plus qu'un mauvais souvenir. Il a toujours eu la force d'un pou de combat.

/fø/ passage

Ce feu a pris au troisième et quatrième étage. J'ai vu de belles choses avec des feux de Bengale. Un feu s'est déclaré en Inde et au Pakistan. L'incendie est provoqué par le feu d'une poubelle. Trop de feu dénature la qualité de la viande. Le taxi n'a pas attendu son feu rouge.

/bu/ passage

Le bout du tunnel n'est pas si loin que ça. Ils mettent sur le côté tous leurs bouts durs. Des bouts de robinet traînent par terre chez lui. Elle m'a volontiers donné son bout rassis. Ce bout en bois s'est enflammé tout de suite. Les délégués lui ont remis un bout mural.

CVC condition:

/kɔl/ passage

Le col est obligatoire dans cet institut. Ce col n'est pas fermé à une heure pareille. Les cols pourront être repassés avec ça. Vous serez impeccables avec ces cols blancs. A navale les officiers ont des cols marins. Etonnamment nous abandonnons certains cols rouges.

/sik/ passage

Les sikhs sont en rang devant le temple hindou. Le sikh ne doit pas se couper les cheveux. Des sikhs attendent en priant la venue de Dieu. Je n'ai jamais vu autant de sikh ici. Ce pays accueille de nombreux sikhs gris. En ces jours de prospérité plusieurs sikhs chantent.

/kur/ passage

La cour d'honneur est ouverte au public. Un cours de math sera donné en amphi. Les cours boursiers n'en font qu'à leur tête aujourd'hui. Demain je vais suivre un premier cours d'arabe. Tu déploieras tous tes savoirs pour ce cours unique. Certains professeurs rendent leurs cours intéressant.

/set/ passage

Les sets de tables ont été disposés. Le dernier set est remporté par le champion. Plusieurs sets en argent furent volés hier. Notre invité étranger offre des sets japonais. Beaucoup ont entendu la rumeur du set doré. Autrefois ces familles avaient un set complet.

/kɔr/ passage

Le corps des marines est parvenu à la paix. Ce cor tant attendu sonne la fin des combats. Des cors en bronze produisent un son unique. Nous aimons le timbre grave des cors d'antan. Les musiciens de l'orchestre portent les cors dorés. Vous serez surpris d'entendre ces cors magnifiques.

/sit/ passage

Un site internet ne peut être piraté. Le site archéologique a été piétiné. Quelques sites industriels français sont vides. De nos jours ils espèrent tous que les sites ouvrent. J'espère que d'ici un an des sites ferment. Dorénavant il faudra que ce site publie.

/kul/ passage

Une coule est une robe à cape pour les moines. Cette coule grise trop longue ne m'appartient pas. La coule du frère bénédictin est brodée main. Je vais changer de ce pas votre coule usée. Les religieux souhaitent récupérer leurs coules bleues. Cette année le nouveau pape a une coule parée.

/sek/ passage

Le sec se marie mieux avec le foie gras. Des secs sont à prévoir la semaine prochaine. Certains secs ne peuvent se marier à la viande. Un relief sous-marin peu profond est un sec bleu. Dans le désert égyptien tu peux voir ces secs arides. L'agence ne peut prévoir que quelques secs annuels.

/rys/ passage

Les russes boivent de la vodka dès le matin. Un russe est venu me voir à l'ambassade. Des russes ont été aperçus près de la rivière. L'Europe s'est bâtie grâce aux russes du nord. L'agence spatiale accueille des astronautes russes préparés. Cette ville subit une influence russe importante.

/bag/ passage

La bague du marié est trop grande pour son doigt. Ces bagues dorées valent au moins une maison. Des bagues sont proposées après la cérémonie. Le médecin lui a proposé les bagues dentaires. Les époux se sont échangés certaines bagues jolies. Je l'ai accompagnée pour choisir sa bague carrée.

/ruz/ passage

La ville de Rouze est une commune française. La Rouze d'antan était grande, peuplée et connue. Cette Rouze dépérit au fil des années. Depuis son départ je n'ai vu qu'une Rouze pâle. Maintenant les guides préfèrent aller à Rouze en bus. Une navette relie la gare de certains Rouzes urbains.

/bɛk/ passage

Le bec de cette chouette est drôlement amoché. Un bec jaune distingue la corneille du corbeau. Ce bec benzène est utilisé par quelqu'un d'autre. Les ornithologues aiment observer les becs d'oiseau. Plusieurs spécialistes détaillent ces becs bleus. Toutes ces espèces présentent des becs cornus.

/ryz/ passage

Cette ruse infantile est vieille comme le monde. La ruse est la meilleure arme dans ce royaume. Une ruse trompe les ennemis de la couronne. Dans le passé j'ai été victime de ruses parfaites. Les enfants terribles font de belles ruses méchantes. De tout temps les plus courtes ruses sont les meilleures.

/bak/ passage

Le bac était très simple pour les lycéens. Ces bacs à linge sont en plastique recyclable. Des bacs ont été mis à disposition des filles. Malgré la chaleur de ce mois les bacs tiennent. Les jeunes hommes nettoient quelques bacs de cuisine. Il préfère corriger un bac scientifique.

/rus/ passage

Cette rousse est bien connue des services secrets. La rousse chante avec son groupe musical. Les rouses étaient considérées comme des sorcières. Il aimerait photographier des rouses belles. Nous voudrions consulter une rousse jalouse. Preuve est faite qu'il existe certaines rouses joviales.

/bɛg/ passage

Ce bègue parle avec éloquence en public. Un bègue peut exercer le métier de comédien. Quelques bègues sont présents durant le cours. L'orthophoniste rencontre des bègues sympathiques. Il faut souvent encourager ces bègues timides. C'est bien de travailler avec les bègues volontaires.